PART I: Hydrological Analysis of the 2000-2001 Drought in South Florida

Wossenu Abtew, R. Scott Huebner, and Simon Sunderland

PREFACE

The 2000-2001 drought in Central and South Florida was a significant hydrologic and water management event. During this period, critical water supply shortage was experienced by all sectors of water users. The continual monthly rainfall deficit compounded the decline in storage volume, forcing the Water Management District to declare a drought emergency and implement Water Use Restrictions. Water quality and biological monitoring were expanded, and daily, weekly, and monthly drought reports were generated to assist water management decision making and inform the public on the status of the hydrologic system. The South Florida Water Management District took the lead in facilitating a multi-agency response to this event, coordinating a series of decisions and actions to protect the public interest to the maximum extent possible.

Documentation of such an event is necessary to preserve the experience for the benefit of future managers of such events. Thus, the District is producing the *2000-2001 Drought Report*. The report is divided into three parts. *Part I: Hydrologic Analysis of the 2000-2001 Drought in South Florida* is presented here. Part I summarizes the hydrologic and water resources conditions from October 1, 1999 through September 30, 2001. Historical hydrologic analysis is also provided for a comparative understanding of the magnitude of the drought. *Part II: Water Management During the 2000-2001 Drought in South Florida* addresses water management during this period of record-low rainfall and highly restricted water supply. It provides a record and synoptic view of the drought management process, including valuable information for future drought monitoring and drought management. Finally, an Executive Summary will be produced containing a synopsis and summary of the major findings.

Many staff members worked to make the Drought Report a reality. Principal recognition for Part I goes to Wossenu Abtew, Lead Engineer with the Environmental Monitoring and Assessment Department and the primary author. Other key contributors include R. Scott Huebner, Lead Engineer with the Environmental Monitoring and Assessment Department, and Simon Sunderland, Staff Hydrogeologist with the Water Supply Department. Finally, special thanks go to the editorial team, chapter authors and support staff. Their assistance was invaluable.

Sincerely,

Naomi S. Duerr

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Wossenu Abtew and R. Scott Huebner

SUMMARY

The 2000–2001 drought and water shortage in Central and South Florida was a significant hydrologic and water management event that warrants analysis and documentation for guidance during future droughts and in mitigation decision making. This report summarizes hydrologic and water resource conditions from October 1, 1999 through September 30, 2001. Historical hydrologic information is provided for a comparative understanding of the drought's magnitude.

CENTRAL AND SOUTH FLORIDA HYDROLOGIC SYSTEM

The South Florida Water Management District's jurisdiction extends from Orlando in Central Florida to the Florida Keys in southernmost Florida. (**Figure 1-1**). The center of the hydrologic system is Lake Okeechobee, with an area of 680 square miles and a mean depth of 8.86 feet. Historically, Lake Okeechobee attained a maximum water level of 18.76 feet NGVD (National Geodetic Vertical Datum) on November 2, 1947. The lowest water level ever recorded for the lake was 8.97 feet NGVD, set during the 2000–2001 drought on May 24, 2001. Lake Okeechobee provides water to surrounding communities, the Everglades Agricultural Area, and the St. Lucie and Caloosahatchee river basins. The lake also replenishes canal levels in Palm Beach, Broward and Miami-Dade counties. Lake Okeechobee has been managed under a regulation schedule that ranges between water supply and flood control. The history of water levels in the lake is a good indicator of wet conditions and drought, that is, low lake levels correspond to historical droughts.

The upper Kissimmee Chain of Lakes (lakes Myrtle, Alligator, Mary Jane, Gentry, East Tohopekaliga, Tohopokaliga, and Kissimmee) are principal sources of inflow to Lake Okeechobee. The upper Kissimmee watershed has an area of 1,596 square miles (Guardo, 1992). Inflow from the Kissimmee River (C-38 canal) at structure S-65 contributes, on average, 69 percent of the inflow into Lake Okeechobee through structure S-65E at the lake's northern end. The lower Kissimmee River Basin (727 square miles) also contributes flow through S-65E. The Lake Istokpoga Surface Water Management Basin (418 square miles) also drains into Lake Okeechobee. Lake Istokpoga is a 43.27 square-mile shallow lake, with outflow through structure S-68 into the Surface Water Management Basin. The remaining major water sources contributing to Lake Okeechobee inflow are direct rainfall, Fisheating Creek, the Taylor Creek-Nubbin Slough Basin, reverse flow from the Caloosahatchee River, the St. Lucie Canal, and back pumping from the Everglades Agricultural Area.

In the south, Water Conservation Areas WCA-1 (220 square miles), WCA-2A (164 square miles), and WCA-3A (767 square miles) are part of the water storage and distribution system. All have specific regulation schedules. From north to south, flood control and water supply are regulated through three systems of canals, stormwater detention ponds, lakes, impoundments, and water control structures. The major hydrologic components of the South Florida Water Management District are depicted in **Figure 1-1**.

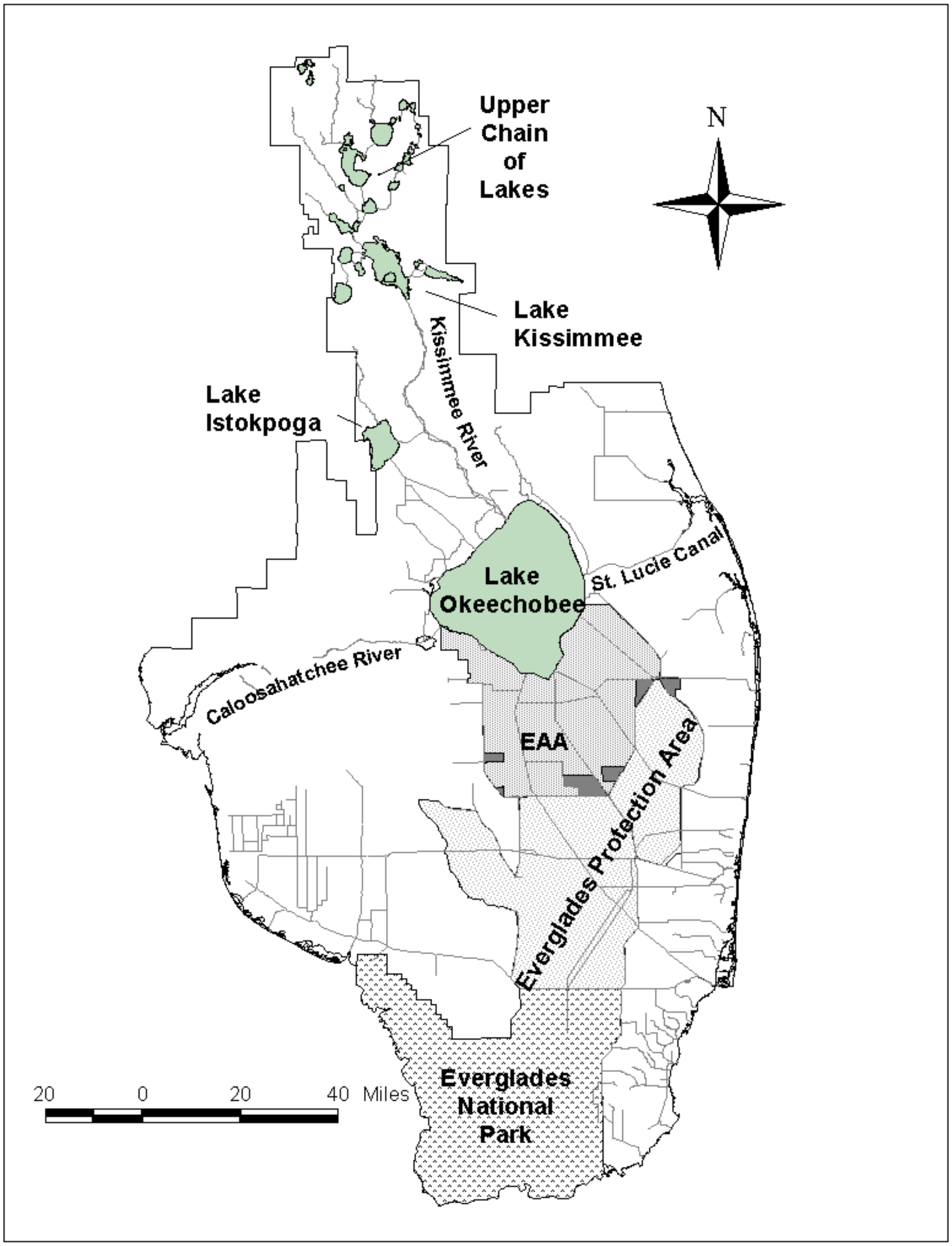

Figure 1-1. Major hydrologic components of the South Florida Water Management District

DROUGHTS IN SOUTH FLORIDA

TYPES OF DROUGHTS

Droughts are important meteorologic, social, and economic events in most parts of the world. Although the type and severity of drought varies from place to place, it is generally associated with a shortage of water for a given duration of time for a designated activity. Broadly, the water source could be soil moisture, rainfall, snow pack, stream flow, groundwater, and surface water storage. Droughts are classified as agricultural, meteorologic, hydrologic, and water management (Subrahmanyam, 1967; Benson and Gardner, 1974). Agricultural drought is an evapotranspiration deficit (Palmer, 1965). Agricultural drought is also characterized as short-term moisture deficiency in the shallow plant root zone. Meteorologic drought occurs when an extended period of below-normal precipitation prevails. Hydrologic drought is the result of reduction in surface water and groundwater due to the amount and/or spatial and temporal distribution of precipitation. Hydrologic drought has long-term effects on regional and local surface water and subsurface water supplies. Water management drought is characterized as water deficiency that occurs because of the inability to develop and manage an integrated surface and subsurface water supply system to overcome water deficits (Benson and Gardner, 1974). Other types of drought cited in the literature are climatological and atmospheric. A drought lasting from one to three months is considered short-term; a drought lasting from four to six months is considered intermediate; and a drought lasting more than six months is considered long term (Golden and Lins, 1986).

Drought can occur when one or more of three components are in place. The first component is a change in the magnitude and temporal distribution of water sources, such as precipitation; the second is a change in the amount and temporal variation of water use or demand; and the third component is society's inability to develop and optimally manage an integrated water supply system. Historical comparison of hydrometeorologic data must be coupled with historical changes in land use, water use (demand), and the water management system for comparative analysis of droughts. Drought impacts can be measured in loss of agricultural products, inadequate public water supply, loss of soil by wind erosion and subsidence, saltwater intrusion into freshwater aquifers, fires, other economic losses associated with water use, and ecological effects. This report summarizes historical and current droughts and water shortages in Central and South Florida.

HISTORICAL DROUGHTS

Drought is a relatively common phenomenon in North America, occurring almost every year in some part of the United States (Kogan, 1995) and in nearly every decade. In Central and South Florida, severe droughts were reported in 1932, 1955–1957, 1961–1963, 1971–1972, 1973–1974, 1980–1982, 1985, 1988–1989, 1990, and 2000–2001 (Benson and Gardner, 1974; Lin et al., 1984; Marban et al., 1989; CSFFCD, 1972, 1974; SFWMD, 1985). Historical droughts and water shortages are marked by declines in lakes, reservoirs, and groundwater levels, declines in rainfall and runoff, and increases in the number and magnitude of wildfires. Analysis of these parameters clearly indicates drought and water shortage occurrences and provides information for anticipation of future drought events.

The severe drought of 1971 resulted in a water restriction declaration on May 3, 1971 (CSFFCD, 1972). Lake Okeechobee reached a minimum stage of 10.29 feet NGVD on June 7, 1971. A rainfall deficit of 43 percent was reported as average for Lake Okeechobee and the Northern, Central, and Southern Everglades for the eight-month period from October 1970 to May 1971. For the same period, the Lake Okeechobee Service Area water demand and delivery was reported to be 734,477 ac-ft. The 1973–1974 drought is comparable to the 1971–1972 drought. For the same months, the rainfall deficit was 47 percent, but with different distribution. Lake Okeechobee Service Area water delivery was 774,568 ac-ft for the period of October 1973 to May 1974 (CSFFCD, 1974). The minimum lake stage of 10.98 feet NGVD was reached on May 31, 1974.

The 1980–1982 drought was one of the most severe droughts ever in South Florida. A more than 20-inch rainfall deficit over two years resulted in the decline of the Lake Okeechobee stage from 17.46 feet NGVD on January 1, 1980 to 9.79 feet NGVD on July 31, 1981. The 7.7-foot drop in water level was attributed to a decrease in rainfall and increases in evaporation and water use. The drought for the Lower East Coast and Water Conservation Areas was relieved by Tropical Storm Dennis (Lin et al., 1984).

The 1984 wet season and the 1984–1985 dry season had rainfall deficiencies that resulted in the 1985 drought. The upper Kissimmee, lower Kissimmee, and Lake Okeechobee rain areas had an average deficit of 14 inches. The Lake Okeechobee water level declined from 15.14 feet NGVD to 11.82 feet NGVD from January 1, 1985 to June 12, 1985. The South Florida Water Management District suspended the interim action plan and initiated backpumping to increase water supply. A water shortage plan was also implemented (SFWMD, 1985).

South Florida experienced a severe drought from September 1988 to August 1989, during which there was a 21-inch rainfall deficit in the Everglades Agricultural Area and the Lower East Coast. The Lake Okeechobee water level declined from 15.95 feet NGVD on September 1, 1988 to 11.06 feet NGVD on August 8, 1989. During the same period a record storage depletion was reported for Lake Okeechobee (1.89 million ac-ft) and the Water Conservation Areas (1.15 million ac-ft) (Marban et al., 1989). The 1990 drought was a continuation of the 1988–1989 drought. From June 1989 through May 1990, nine inches of rainfall deficit occurred District-wide and was most severe in Everglades National Park. Lake Okeechobee supply-side management and water restrictions were implemented to conserve lake water (Trimble et al., 1990). The Lake Okeechobee water level declined from 12.25 feet NGVD on January 1, 1990 to 10.47 ft NGVD on June 21, 1990.

PALMER DROUGHT SEVERITY INDEX

The Palmer Drought Severity Index (PDSI) is used to monitor long-term drought conditions, that is, those occurring over a period of several months (Palmer, 1965). The PDSI uses antecedent moisture conditions, precipitation, temperature, field capacity, and weather trends to compute an index value. Near normal conditions are represented by an index value between ± 0.49; severe droughts have an index value of -3.0 or less. Index values are maintained by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). Monthly values are available from 1895 to present.

The index is standardized to local conditions, allowing it to be used nationally for drought reporting. It is applied to 350 climatic divisions in the United States and Puerto Rico. Florida has seven climatic divisions. The South Florida Water Management District is in Florida divisions 3 through 7 (**Figure 1-2**).

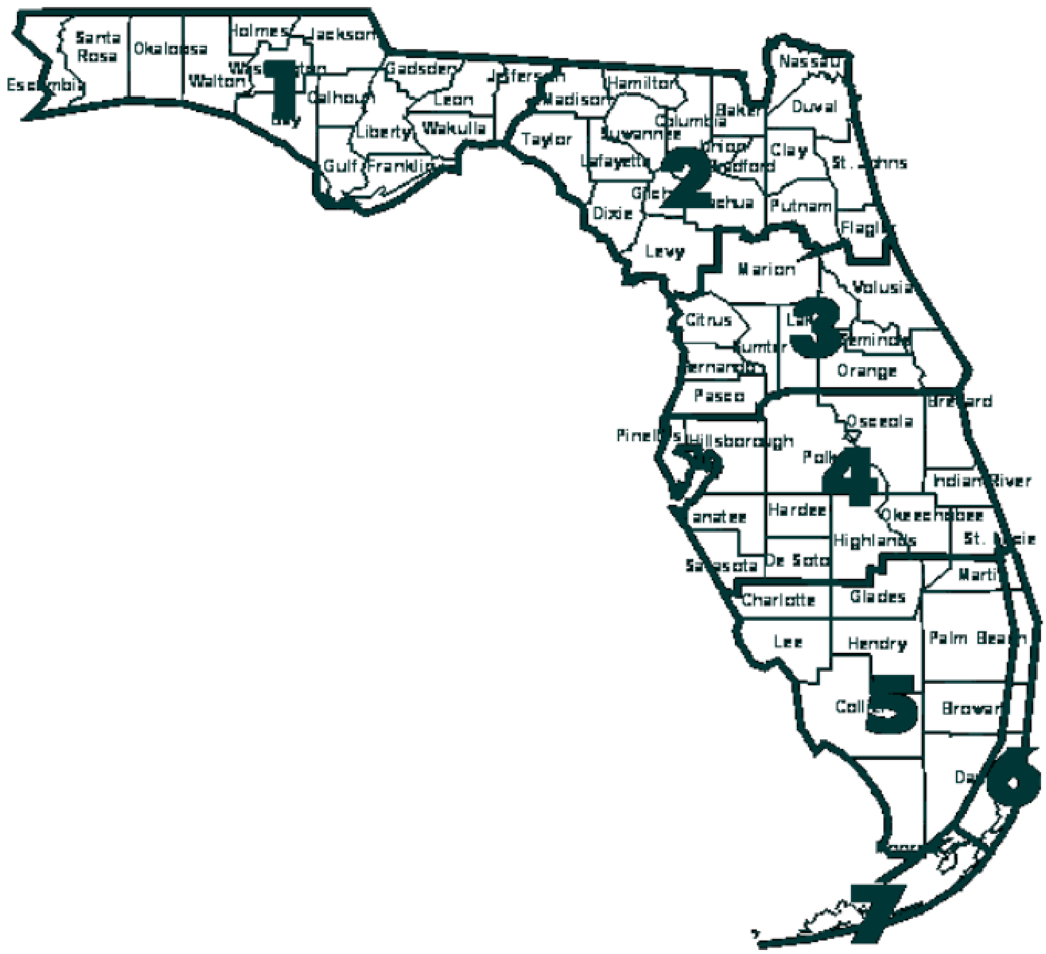

Figure 1-2. Florida climatic divisions (NOAA, Climatic Prediction Center)

Figure 1-3 shows the index values for the five divisions covering the District at the onset of the most recent drought through February 2001. The drought index started declining at the end of 1999 and was most severe in division 3, the region covering the upper Kissimmee area. The index for the upper Kissimmee area began showing drought beginning in the spring of 1998. Two of the divisions, those covering the upper Kissimmee and lower Kissimmee areas, experienced extreme drought conditions during this period.

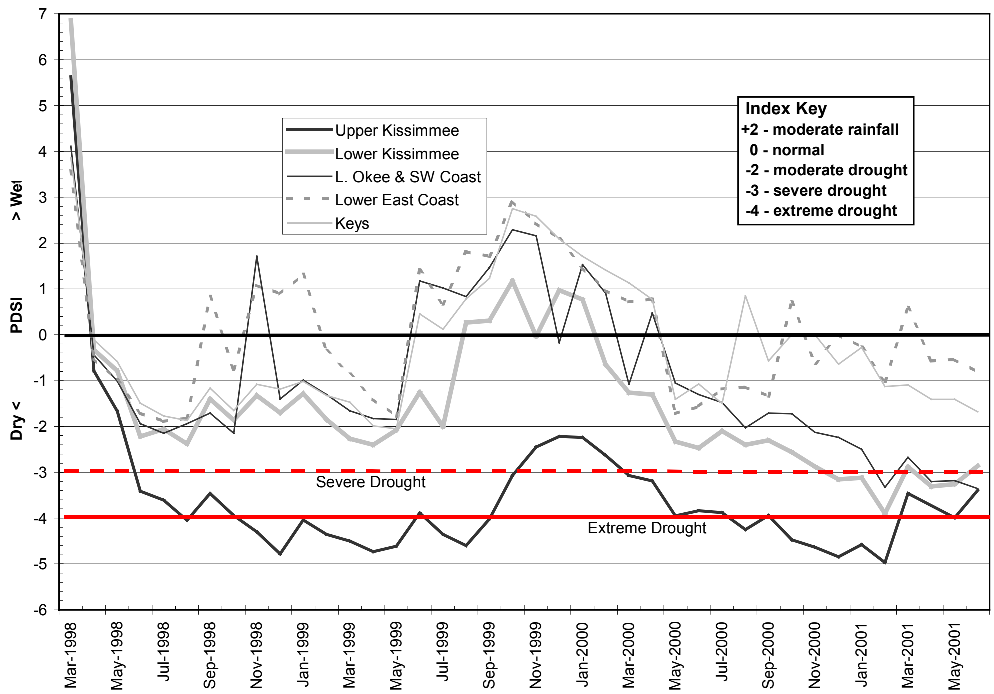

Figure 1-3. Palmer Drought Severity Index, Florida climatic divisions 3, 4, 5, 6, and 7 (March 1998 to June 2001)

Figure 1-4 shows the PDSI for the entire period of record for division 3 (the Upper Kissimmee area). As shown in **Figure 1-3**, this climatic division had the longest and most severe drought during the most recent drought period. Prior to that, the area had not experienced an extreme drought since 1932. The variation in the PDSI from 1895 to September 2001 for the lower Kissimmee area (division 4), Lake Okeechobee, the Lower West Coast, the Agricultural (Ag) areas and the Everglades (division 5), the Lower East Coast (division 6), and the Florida Keys (division 7) is shown in **Figures 1-5** through **1-8**. Severe and extreme droughts are marked.

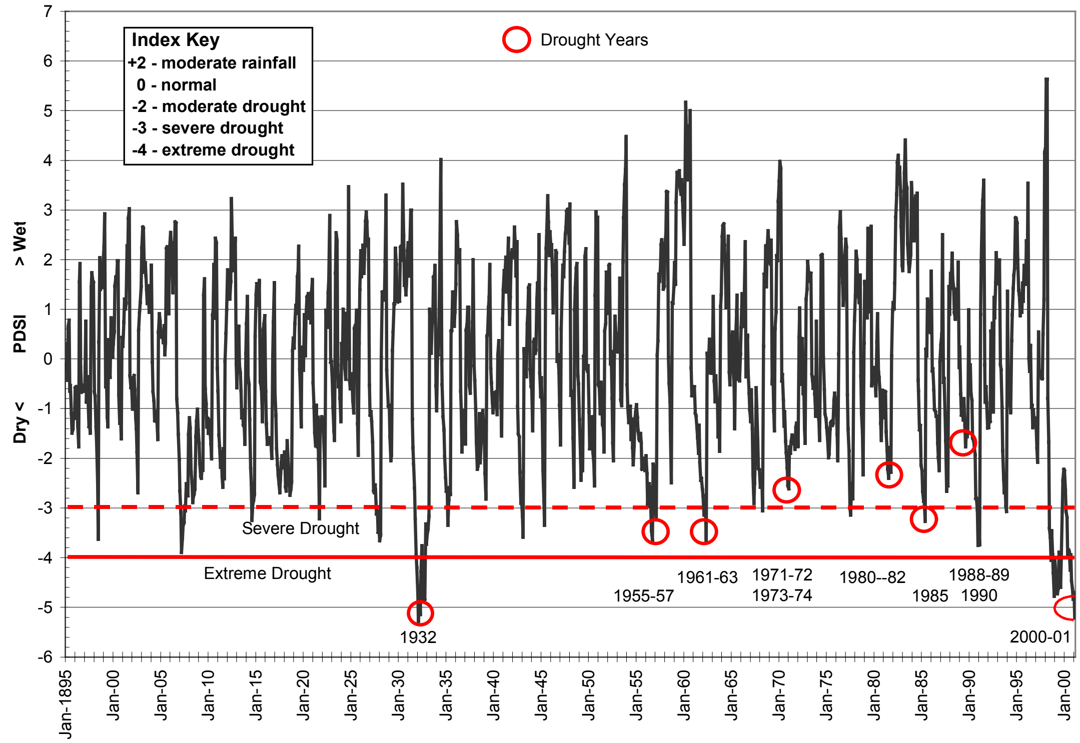

Figure 1-4. Palmer Drought Severity Index, Florida climatic division 3 (upper Kissimmee area), 1895-2001

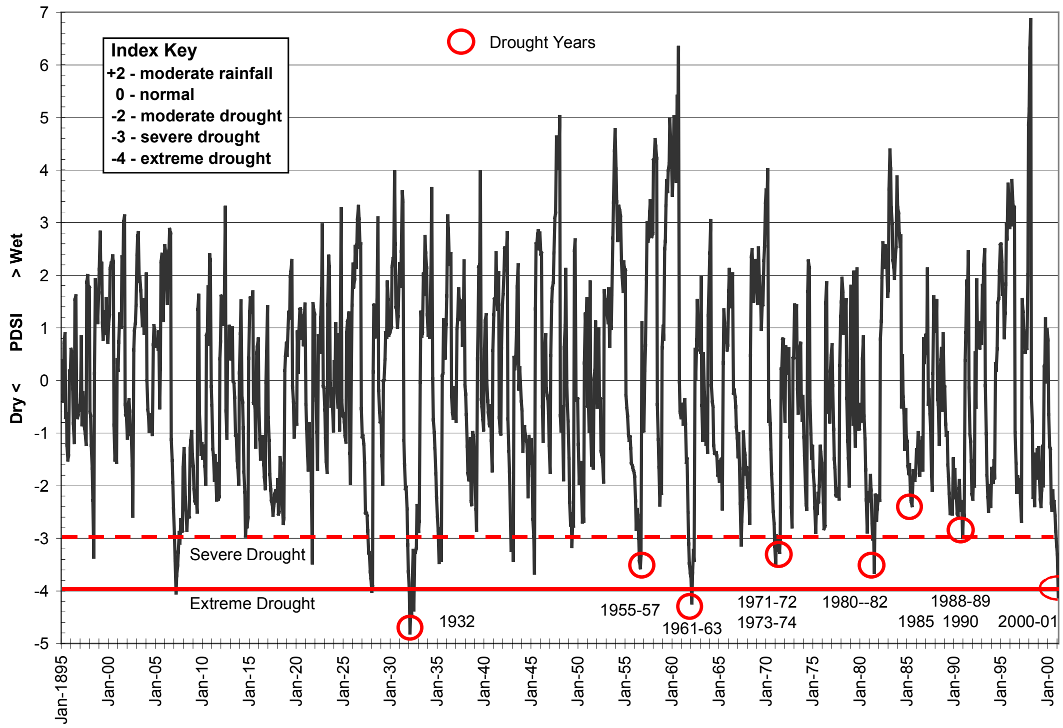

Figure 1-5. Palmer Drought Severity Index, Florida climatic division 4 (lower Kissimmee area), 1895-2001

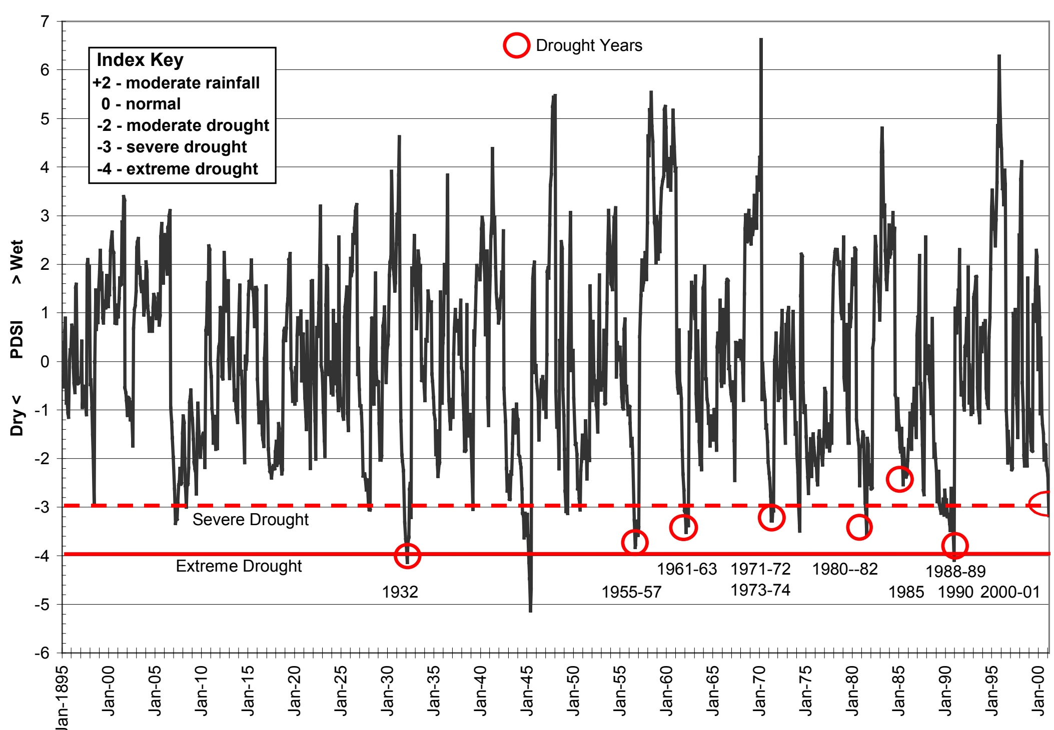

Figure 1-6. Palmer Drought Severity Index, Florida climatic division 5 (Lake Okeechobee, the lower West Coast, the Agricultural areas, and the Everglades), 1895-2001

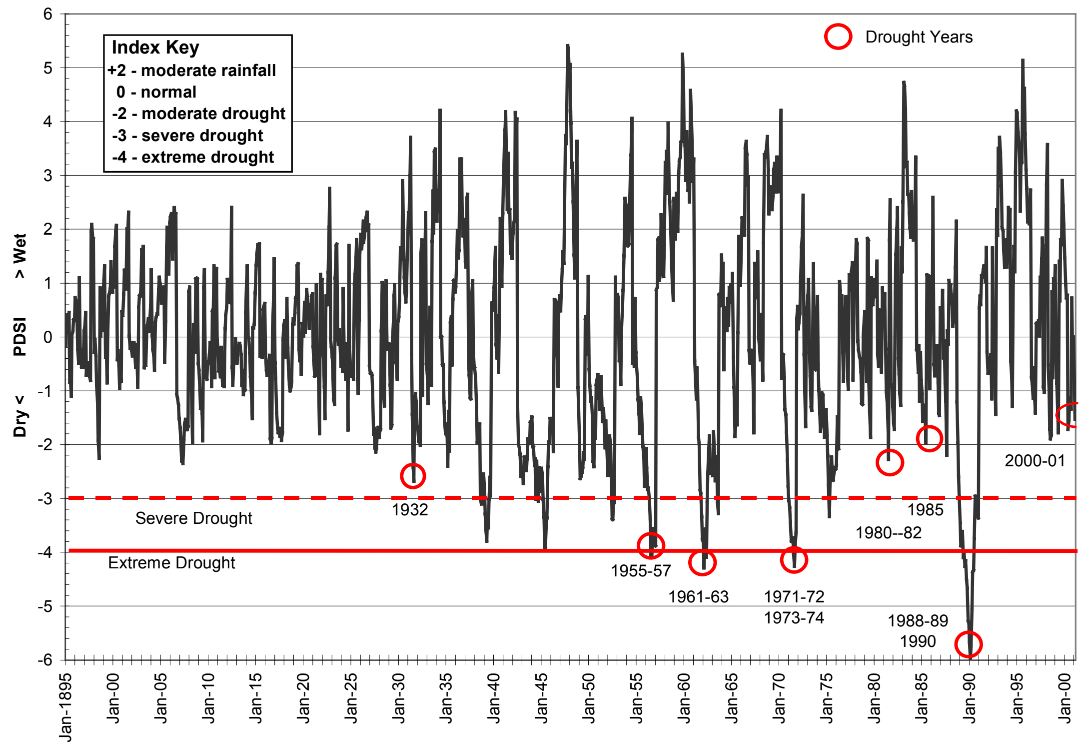

Figure 1-7. Palmer Drought Severity Index, Florida climatic division 6 (lower East Coast), 1895-2001

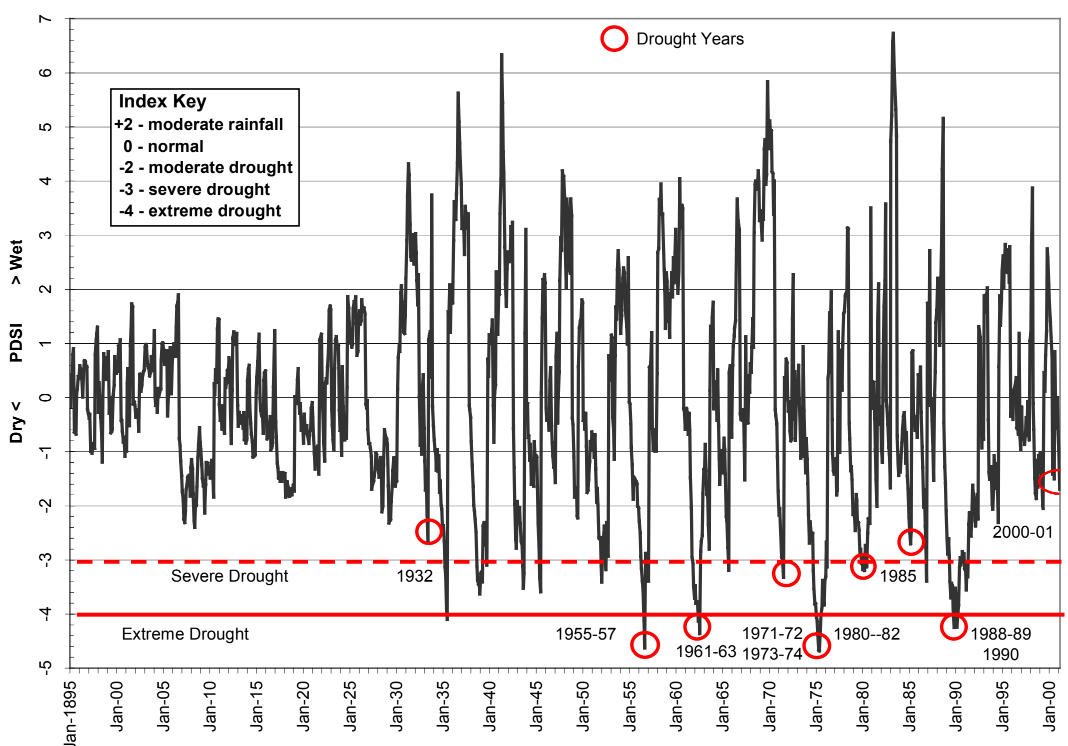

Figure 1-8. Palmer Drought Severity Index, Florida climatic division 7 (Florida Keys), 1895-2001

WILDFIRES

One of drought's more significant impacts on natural resources is the development of conditions that promote the spread of wildfires. **Figure 1-9** shows the number of acres burned per year as the result of wildfires for the period 1981-2001 (Florida DOACS, Division of Forestry, 2001). The data are for all causes of wildfires, including those that were anthropogenic. The largest number of acres burned corresponds directly to drought years (1981, 1985, and 1989). The effects of the La Niña weather pattern that brought lower-than-expected rainfall to the District in 1998 are also shown in **Figure 1-9**, although there was no declared drought that year. **Figure 1-10** depicts acres burned per wildfire in Florida. The year 2001 ranks third in the 21 years of record.

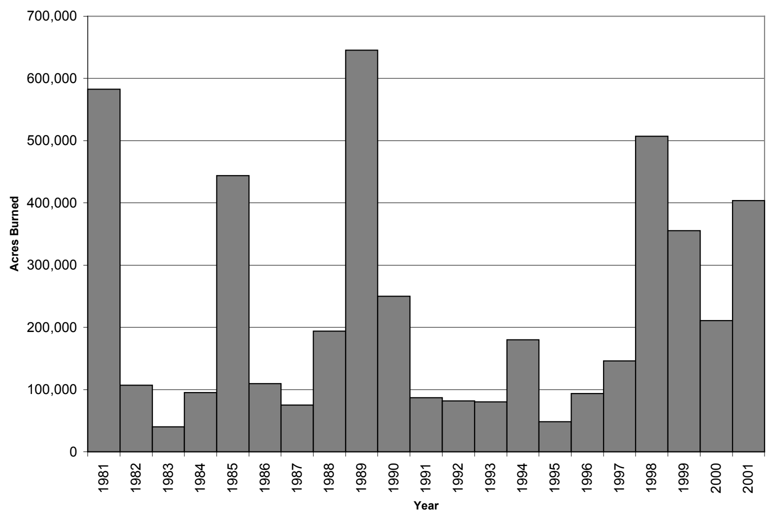

Figure 1-9. Acres burned per year by wildfires in Florida

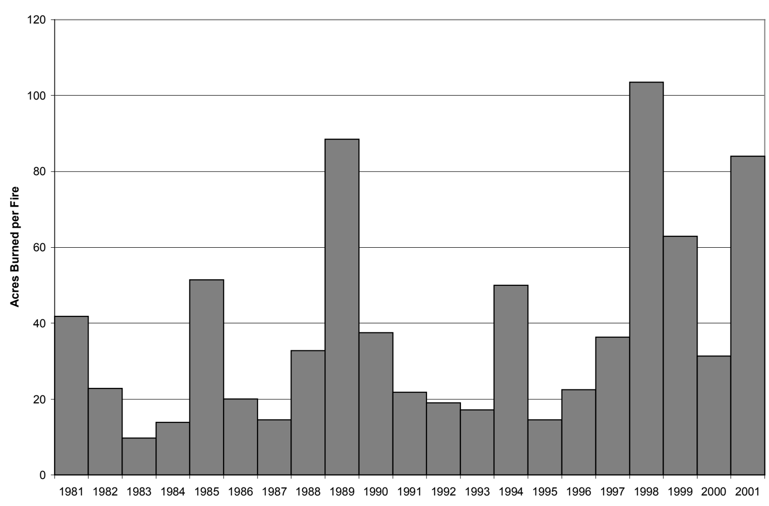

Figure 1-10. Acres burned per wildfire in Florida (1981-2001)

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Chapter 2: Hydrology of the Drought

Wossenu Abtew and R. Scott Huebner

SUMMARY

This chapter provides rainfall analysis for the drought period. Frequency of occurrence of rainfall over the District rainfall areas is presented along with historical rainfall records. Drought period inflows and outflows to major hydrologic components, water levels and storage are presented in comparison with historical records.

RAINFALL

The South Florida Water Management District is divided into 14 rainfall areas for operational purposes. The rainfall areas are shown in **Figure 2-1**. The region is a high-rainfall area, with frontal, convective and tropical system-driven rainfall events. The heaviest rains in South Florida are produced by mesoscale convective systems – extra-tropical in the dry season and tropical in the rainy season (Rosenthal, 1994). In Central and South Florida (excluding the Florida Keys), 57 percent of total summer rainfall occurs on undisturbed sea breeze days, 39 percent on disturbed days and 4 percent on highly disturbed days (Burpee and Lahiff, 1984). The average rainfall in the South Florida Water Management District is 52.8 inches per year. Monthly rainfall statistics for 12 of the rainfall areas are shown in **Table 2-1**. Generally, June is the wettest month, followed by September. The wet season lasts from June through October and accounts for 66 percent of annual rainfall. The driest month is December, followed by January. Generally, runoff generated from wet season rainfall and dry season high-rainfall events is stored in ponds, lakes, impoundments, and aquifers. Excess water is discharged to the ocean to control flooding. At times, critical decision making is required to manage flooding and avoid potential water shortages. Both water shortage and flooding have the potential to occur in any month of the year. Dry periods in Florida result from stable atmospheric conditions that are often associated with high-pressure systems (Winsberg, 1990). These conditions can occur in any season, but are most common in winter and spring.

The Palm Beach rain area has the highest rainfall, followed by the Broward and Miami-Dade rain areas. It can be concluded that the East Coast gets more rain than the inland and West Coast of the District area. Even during drought years there were cases where the coastal rainfall was close to or above average. This was indicated by Palm Beach rain area rainfall in 1931, 1932, and 1972; Miami-Dade rain area rainfall in 1931, and Broward rain area rainfall in 1962 and 1967. Since there are no large impoundments in the coastal urban area, runoff is discharged to the ocean. The historical rainfall record of each rainfall area indicates that drought years have a significant decline from the mean annual rainfall. **Figures 2A-1-1** to **2A-1-12** depict historical annual rainfall for each rain area, along with annual average rainfall amounts. Reported regional drought years since 1932 are marked, and previous drought years can be picked from figures where data is available. These figures show the high frequency of droughts and the variation between rain areas. With the current water management system, drought at the headwaters of Lake Okeechobee would have more impact in terms of water shortage during the dry season than the coastal rain areas.

Figure 2-2 depicts rainfall deficit for each rain area for the 2000 drought and the frequency of occurrence in years of return period. Fifteen percent or higher annual rainfall deficit could result in drought. Temporal and spatial distributions of rainfall and water management are additional factors that determine water availability. The overall impact of drought is dependent on the spatial and temporal distributions of rainfall deficit through the District area. Analysis of the 2000 and 2001 rainfall for each rain area indicates the severity of drought in the rain area and the drainage receiving basins. Comparison of cumulative actual monthly rainfall with cumulative average monthly rainfall for each rain area for the latest drought years is shown in **Figures 2-3** to **2-25**.

Figures 2-4 to **2-26** depict the month-after-month rainfall deficit. The Upper Kissimmee, Lower Kissimmee, Lake Okeechobee, Martin/St. Lucie, East EAA, West Ag., East Caloosahatchee, Southwest Coast and Palm Beach rain areas, with few exceptions, depict mostly deficits since November 1999. Broward, Miami-Dade and WCA-1 and WCA-2 rain areas were relatively less affected by the drought. The Upper Kissimmee, Lower Kissimmee, and Lake Okeechobee areas of the District are the watersheds that contribute most of the inflows to Lake Okeechobee. The 2000 annual rainfall for the three areas had a dry frequency of 1 in 100 years, further indicating the drought's magnitude. The average annual deficit for the three areas was 35 percent. The 2000 annual District-wide rainfall deficit was 25 percent of the historical mean. The drought persisted in most areas through August 2001. For the first eight months of 2001 the East EAA and West Ag. rainfall areas had 31 and 43 percent rainfall deficits, respectively, compared to the average for the same period. Hurricane Gabrielle passed through Central Florida in the middle of September. The hurricane and the associated tropical system resulted in significant rainfall over a large area, contributing to drought relief.

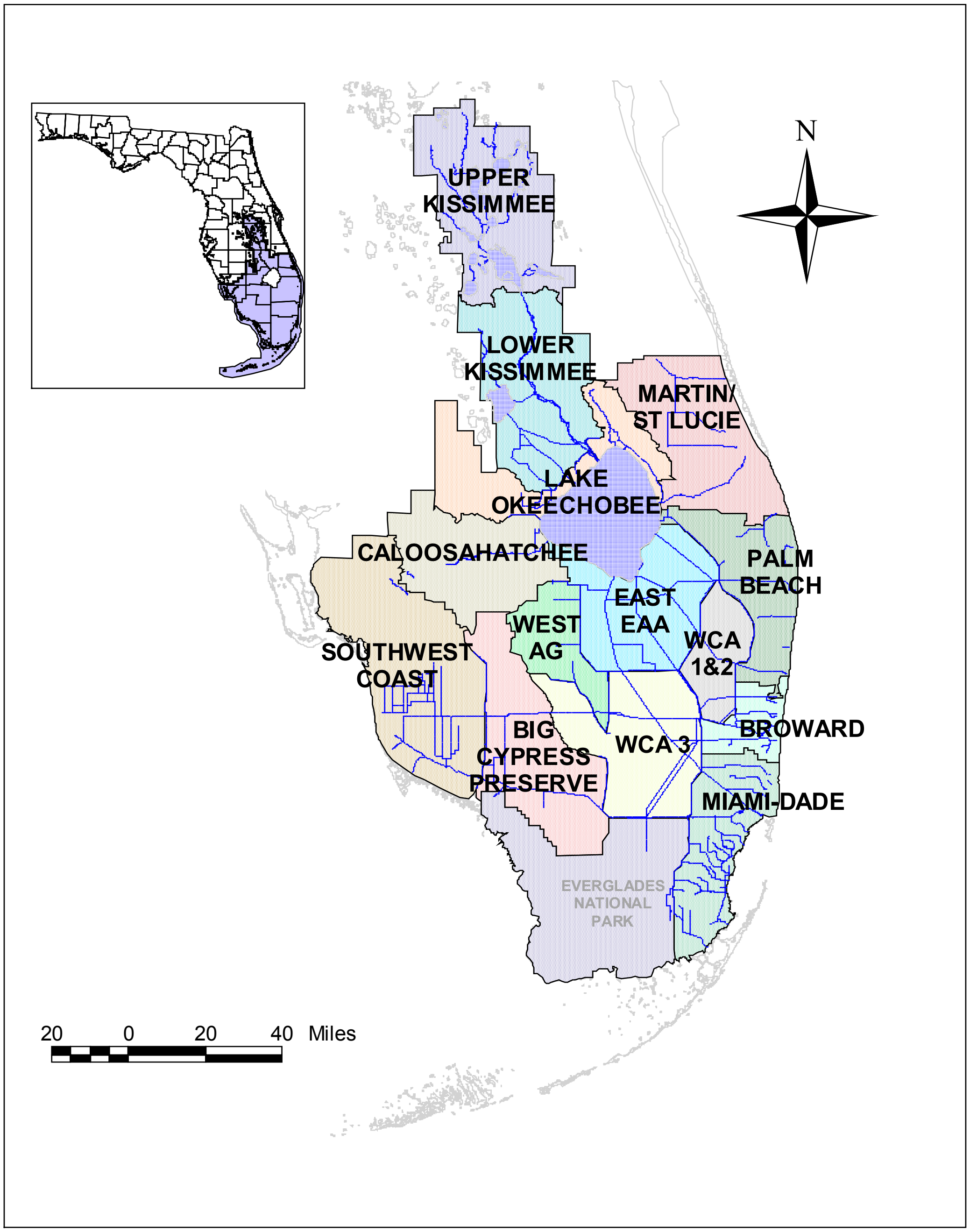

Figure 2-1. South Florida Water Management District rain areas

Table 2-1. Monthly average rainfall (inches) for each rainfall area and the District (Ali and Abtew, 1999)

Month	Upper Kissimmee	Lower Kissimmee	Lake Okeechobee	Martin/ St. Lucie	East EAA	West AG	Caloosa-hatchee	Southwest Coast	Palm Beach	Broward	Dade	WCA1&2	District
January	2.25	1.85	1.85	2.48	2.04	2.48	1.76	1.92	3.03	2.18	2.09	2.25	2.2
February	2.64	2.37	2	2.56	1.94	2.39	2.06	2.15	2.74	2.26	2.01	2.29	2.36
March	3.18	2.76	2.95	3.1	2.78	3.04	2.74	2.46	3.36	2.46	2.28	2.54	2.94
April	2.55	1.92	2.38	3.02	2.76	2.53	2.59	2.21	3.29	3.06	3.02	2.49	2.58
May	4.08	3.84	4.03	4.53	4.77	4.36	4.27	4.03	5.19	5.46	6.06	5.22	4.66
June	7.28	7.26	6.92	6.51	8.41	9.58	8.52	9.13	8.1	8.35	8.28	8.19	7.85
July	7.44	6.58	6.06	6.11	7.5	8.15	7.36	8.73	6.46	6.53	6.21	6.16	6.98
August	6.87	6.2	6.37	6.15	7.61	7.54	7.48	8.26	6.92	7.18	6.99	6.38	7.03
September	6.37	5.33	6.49	7.86	7.61	7.25	7.18	8.2	8.41	7.96	8.32	6.44	7.23
October	3.24	3.07	3.83	6.77	4.29	3.83	3.78	4.05	7.8	7.39	7.32	5.04	4.72
November	2.17	1.84	1.58	2.96	2.06	1.84	1.58	1.55	3.77	3.14	2.78	2.91	2.3
December	2.02	1.43	1.51	2.09	1.71	1.96	1.36	1.43	2.47	2.16	1.75	2.05	1.9
YEAR	50.09	44.45	45.97	54.14	53.48	54.95	50.68	54.12	61.54	58.13	57.11	51.96	52.75

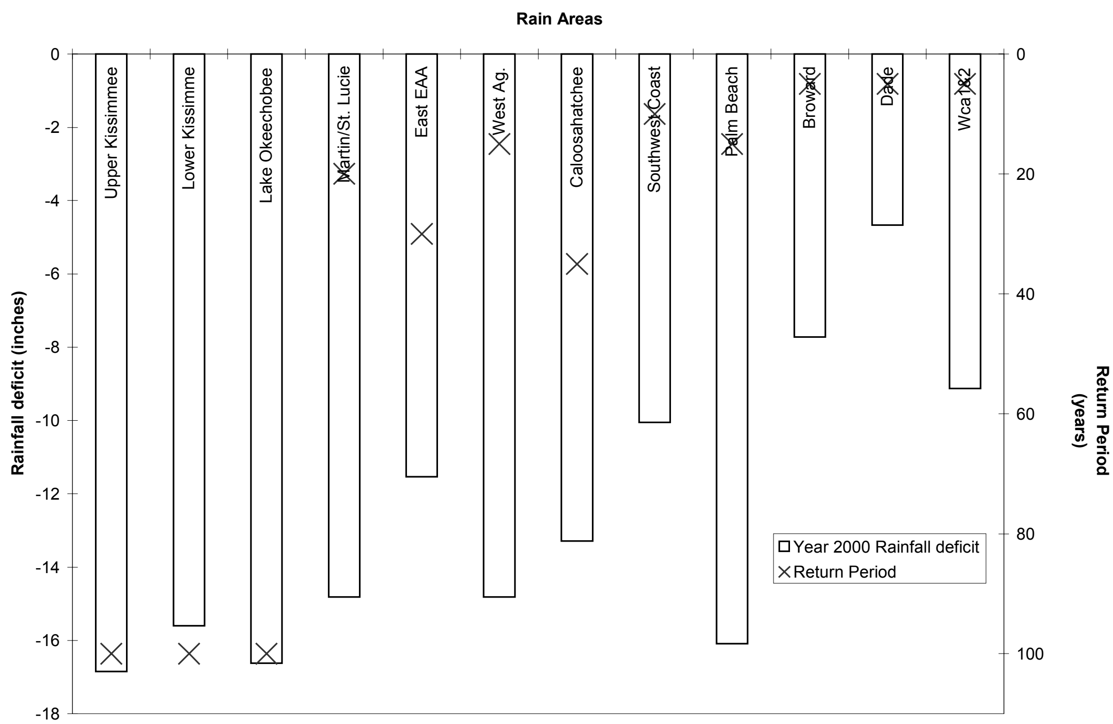

Figure 2-2. Rainfall deficit and return periods for each rain area for 2000

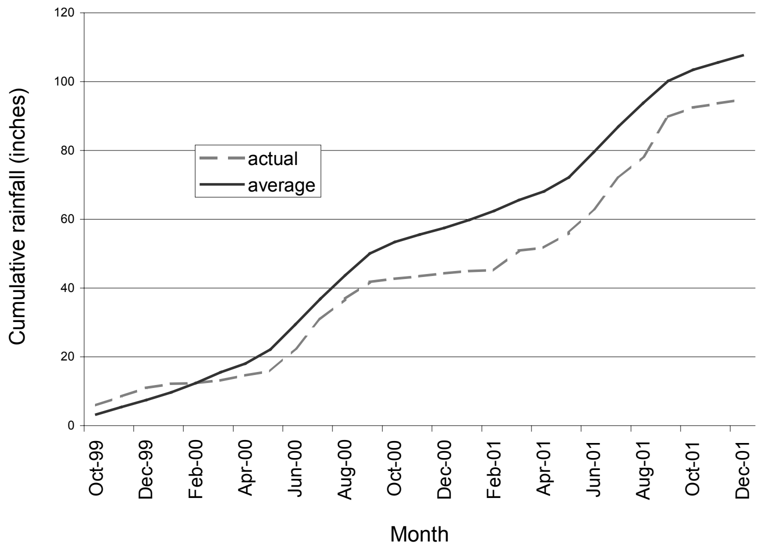

Figure 2.3. Upper Kissimmee rain area actual and average cumulative rainfall

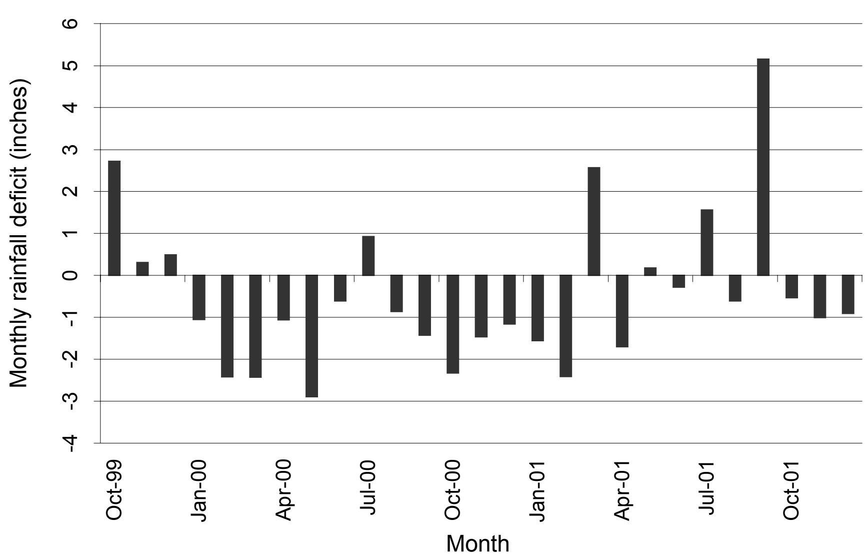

Figure 2-4. Upper Kissimmee rain area monthly rainfall deficit

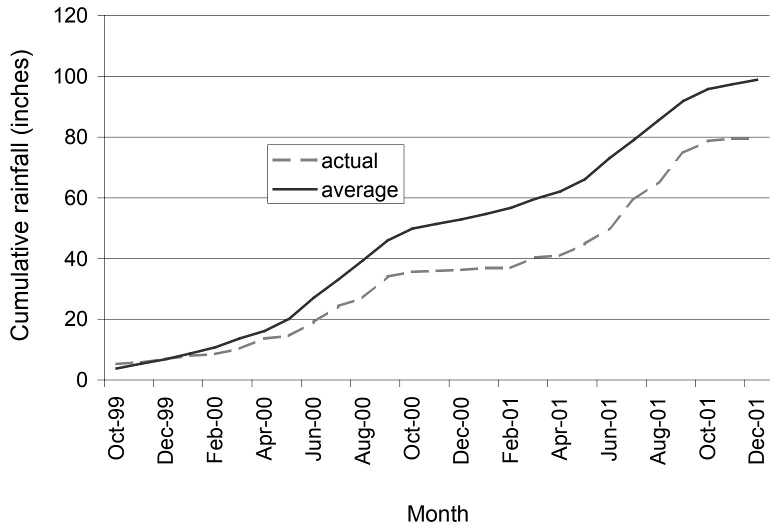

Figure 2-5. Lower Kissimmee rain area actual and average cumulative value

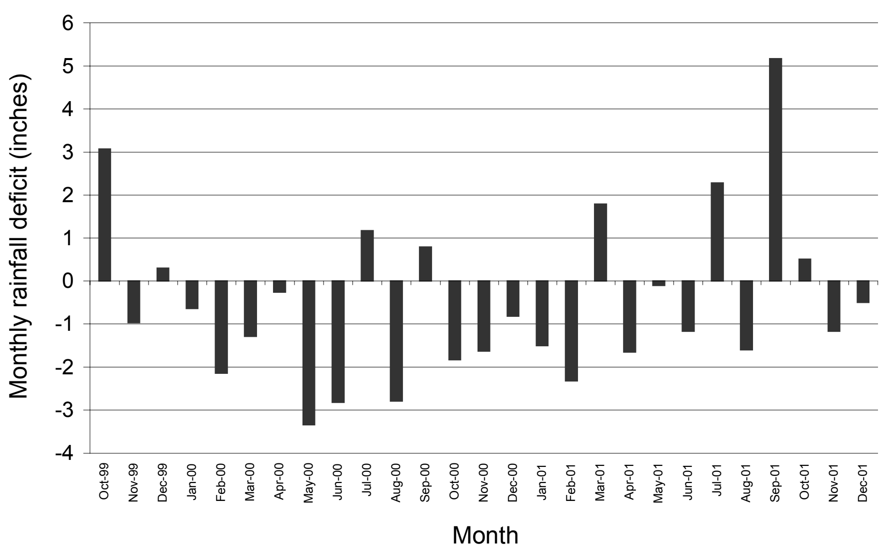

Figure 2-6. Lower Kissimmee rain area monthly rainfall deficit

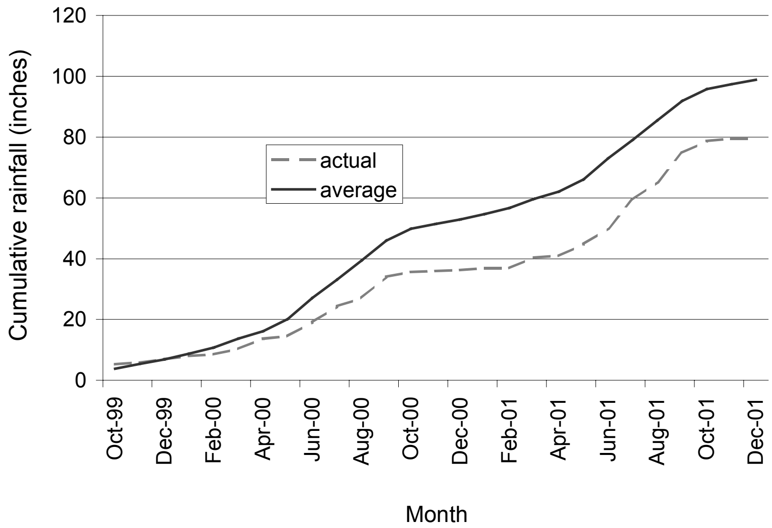

Figure 2-7. Lake Okeechobee rain area actual and average cumulative rainfall

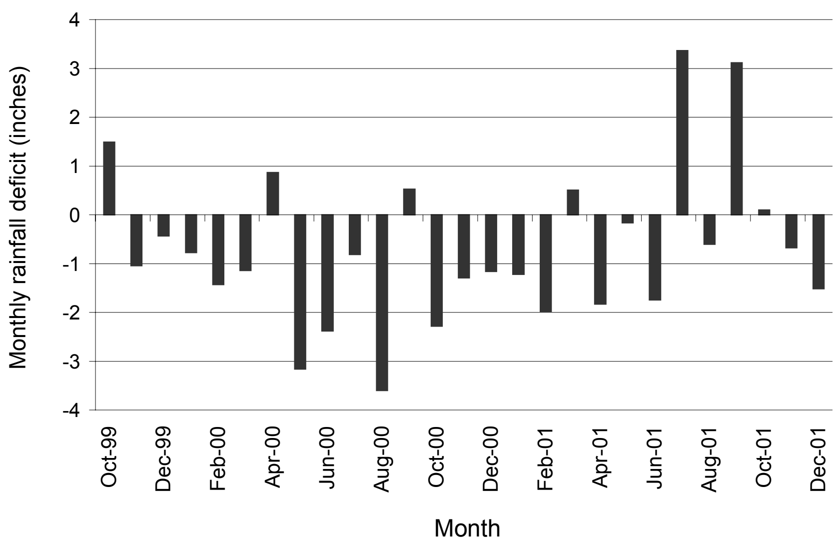

Figure 2-8. Lake Okeechobee rain area monthly rainfall deficit

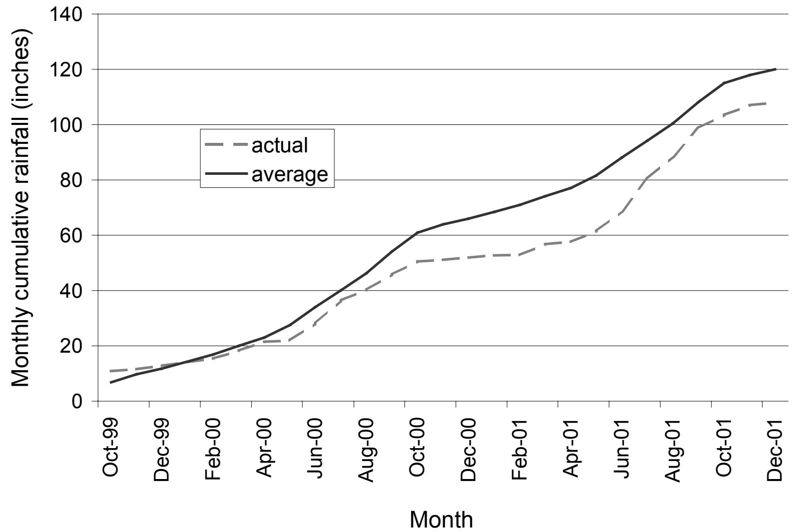

Figure 2-9. Martin/St. Lucie rain area actual and average cumulative rainfall

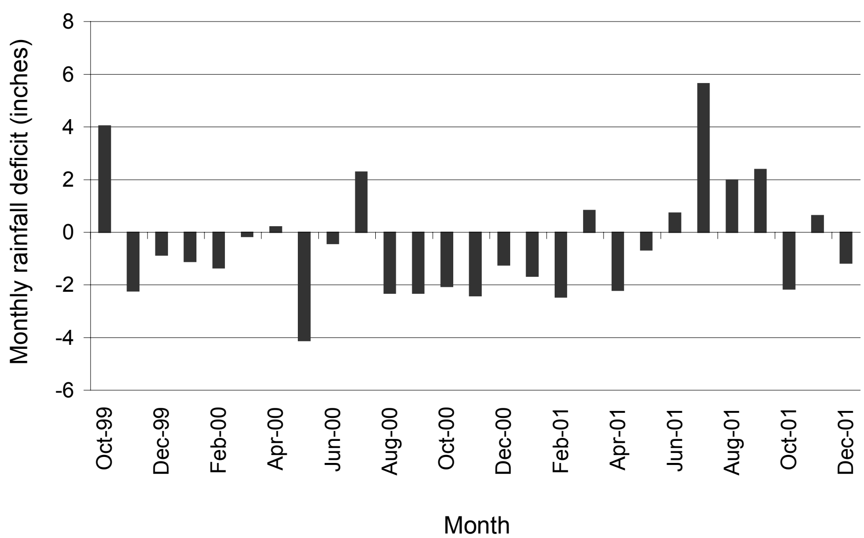

Figure 2-10. Martin/St. Lucie rain area monthly rainfall deficit

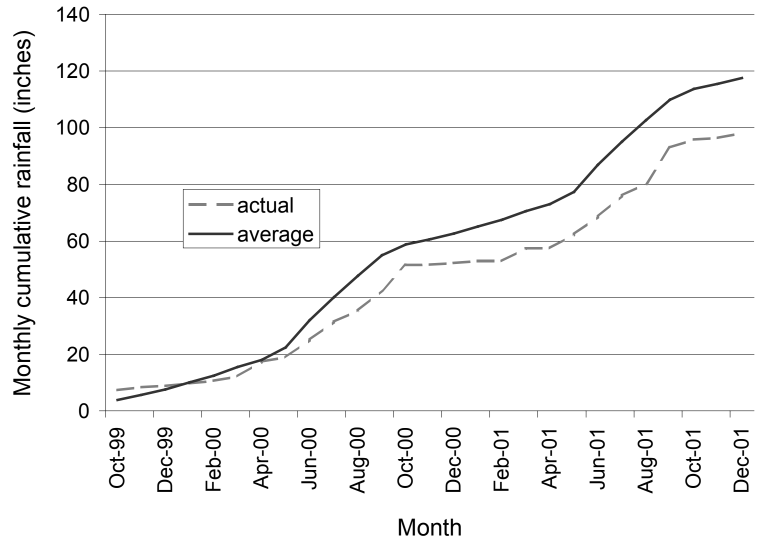

Figure 2-11. East EAA rain area actual and average cumulative rainfall

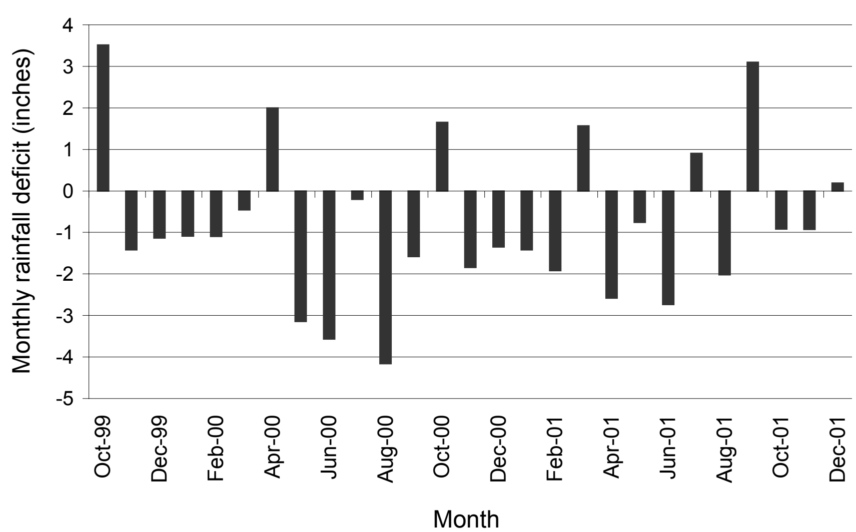

Figure 2-12. East EAA rain area monthly rainfall deficit

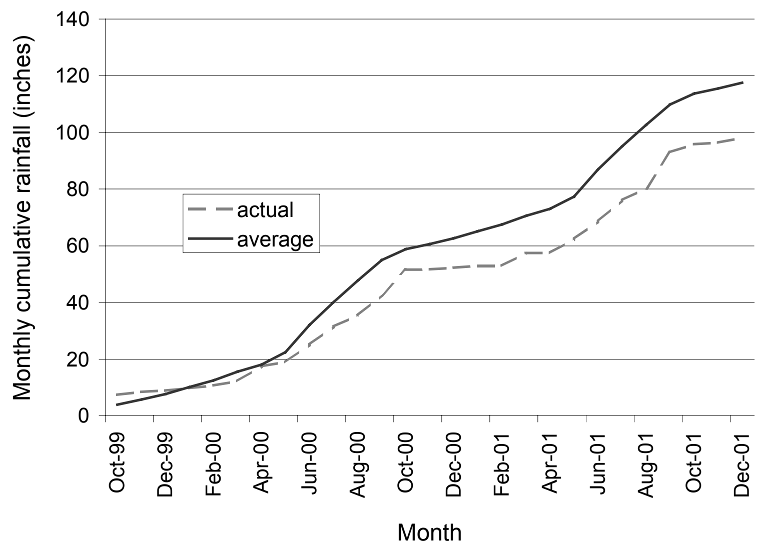

Figure 2-13. West Ag. rain area actual and average cumulative rainfall

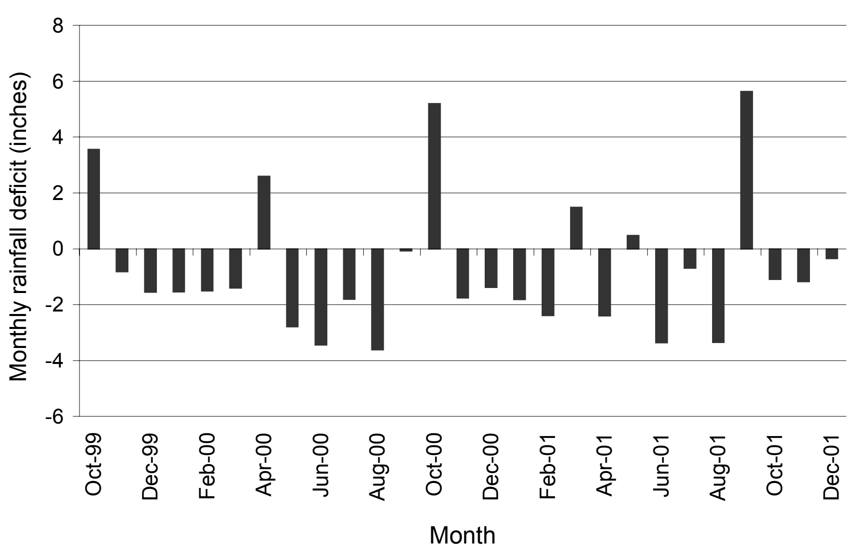

Figure 2-14. West Ag. rain area monthly rainfall deficit

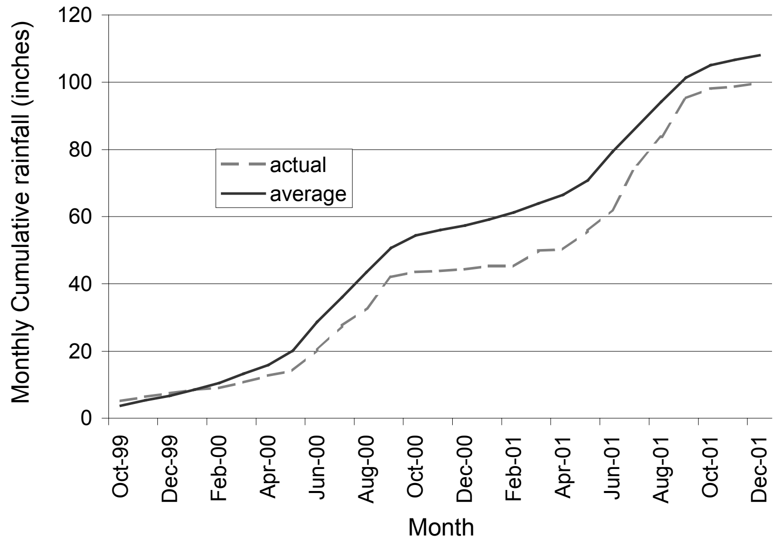

Figure 2-15. Caloosahatchee rain area actual and average cumulative rainfall

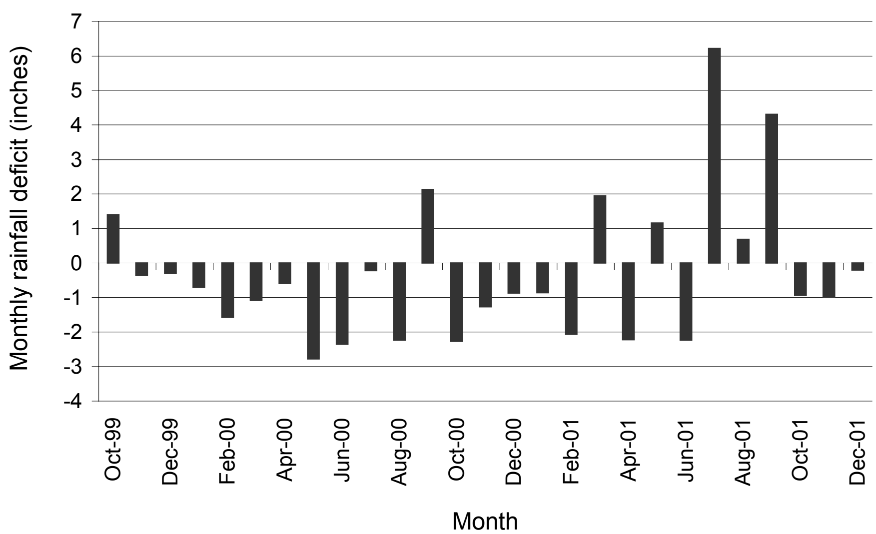

Figure 2-16. Caloosahatchee rain area monthly rainfall deficit

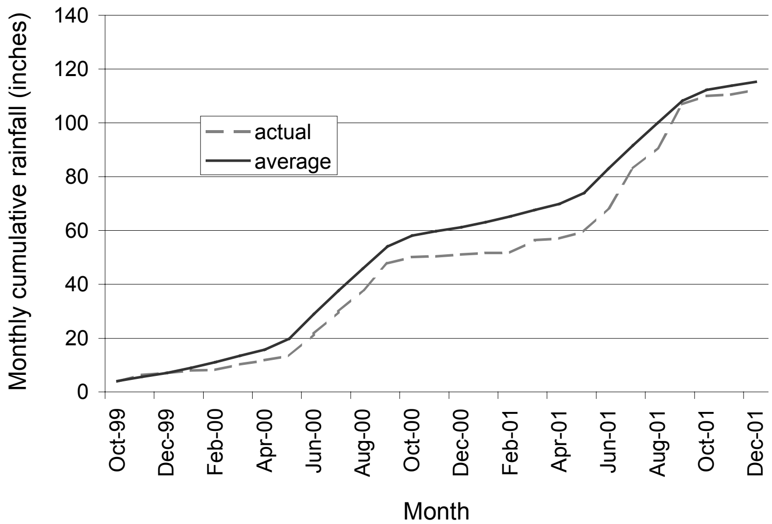

Figure 2-17. Southwest Coast rain area actual and average cumulative rainfall

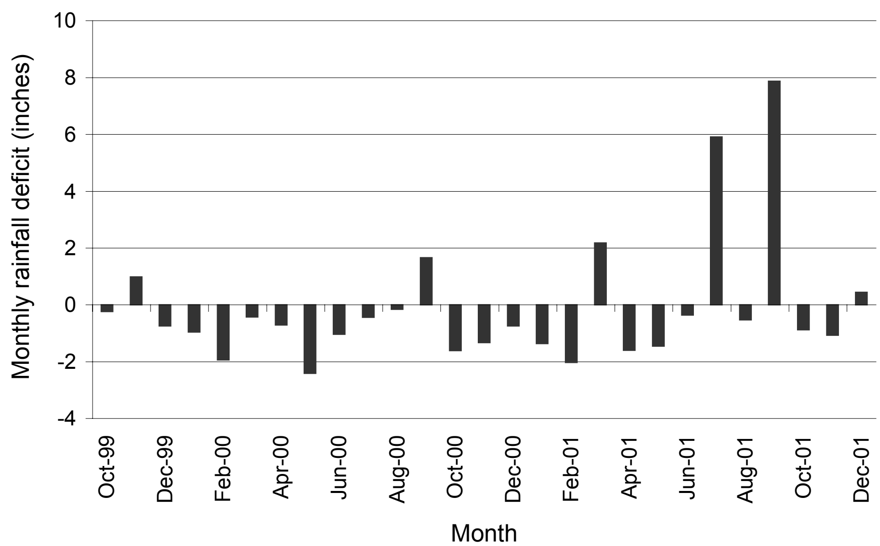

Figure 2-18. Southwest Coast rain area monthly rainfall deficit

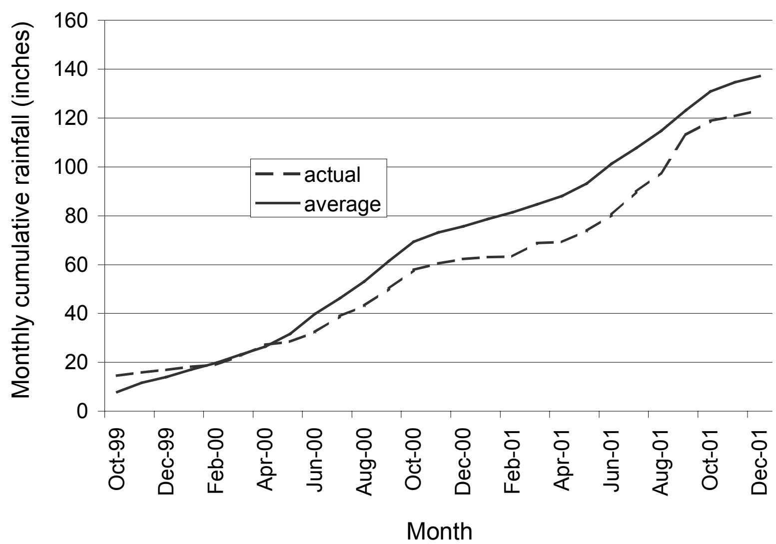

Figure 2-19. Palm Beach rain area actual and cumulative rainfall

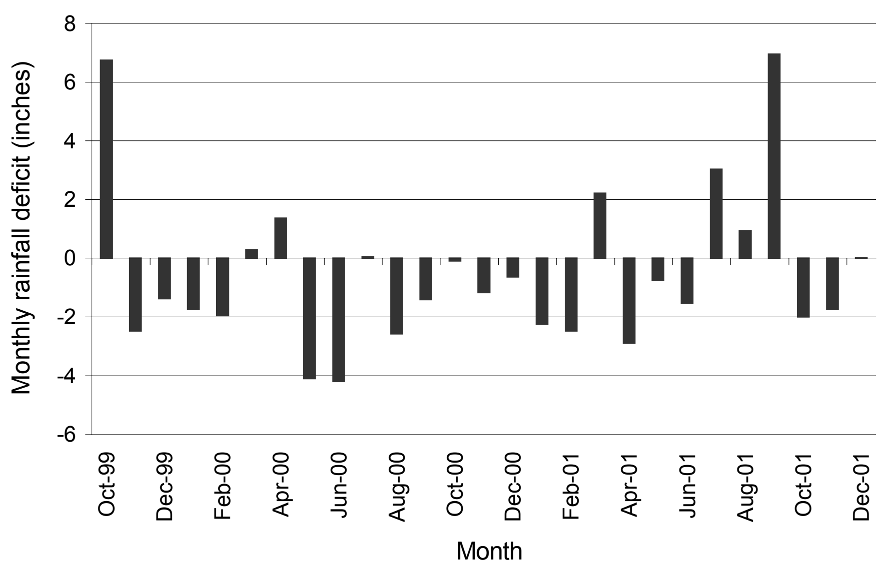

Figure 2-20. Palm Beach rain area monthly rainfall deficit

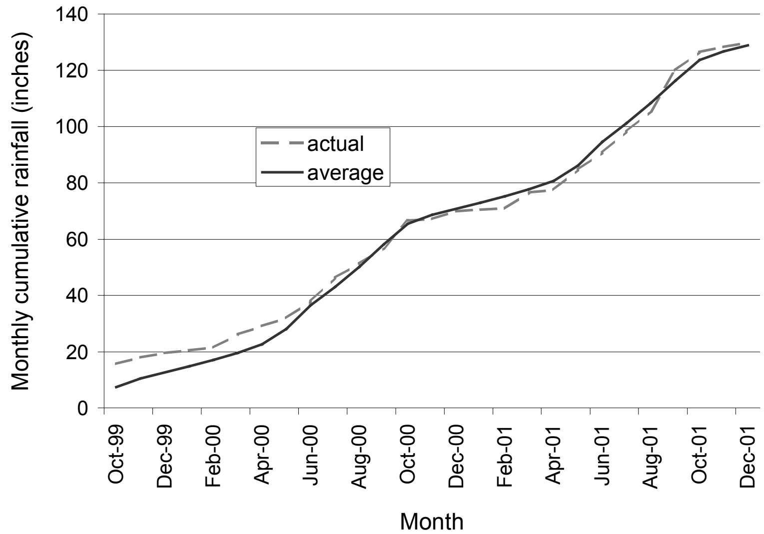

Figure 2-21. Broward rain area actual and average cumulative rainfall

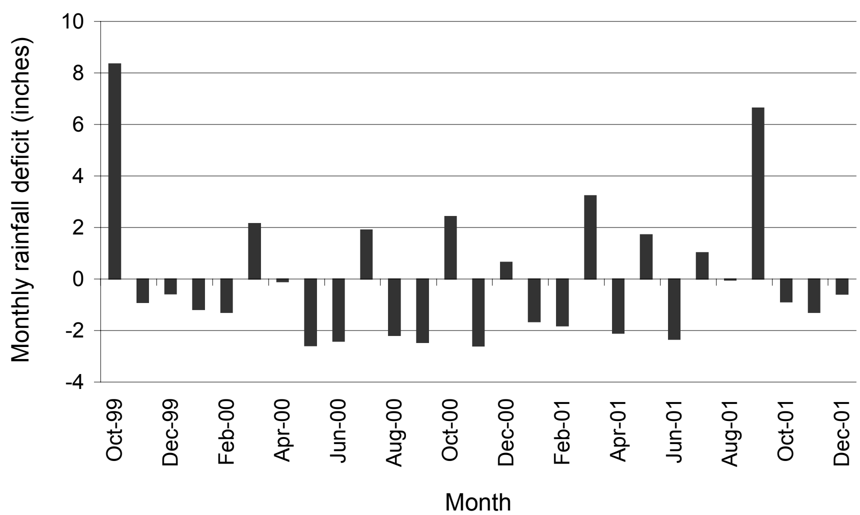

Figure 2-22. Broward rain area monthly rainfall deficit

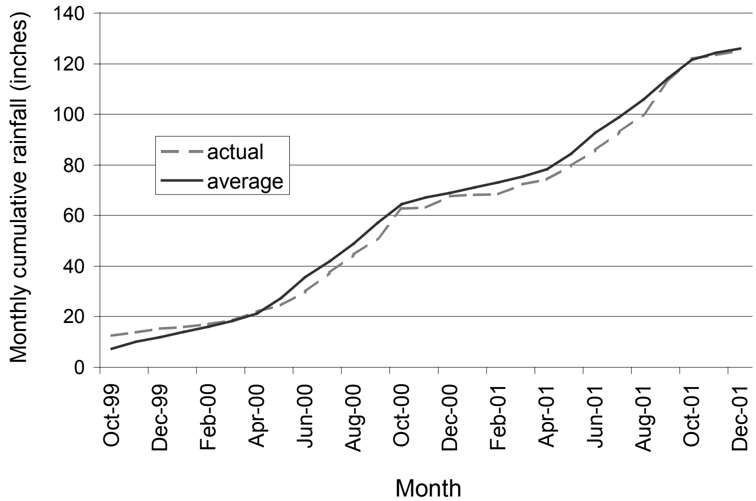

Figure 2-23. Miami-Dade rain area actual and average cumulative rainfall

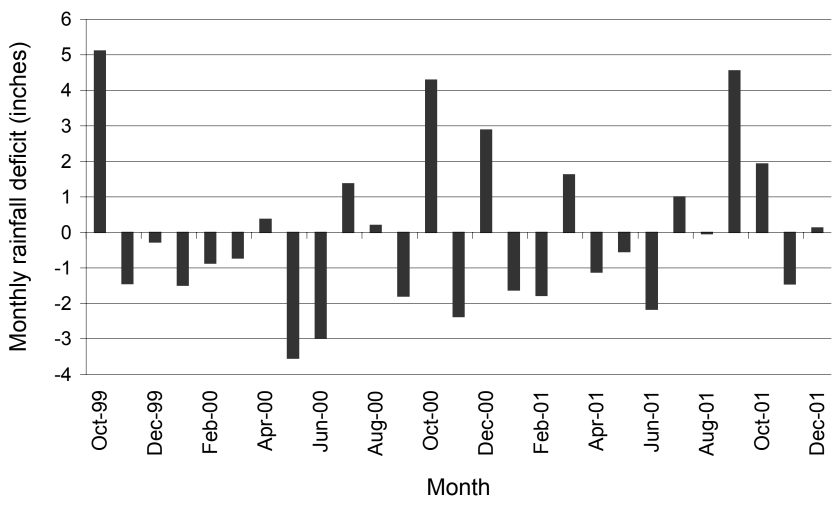

Figure 2-24. Miami-Dade rain area monthly rainfall deficit

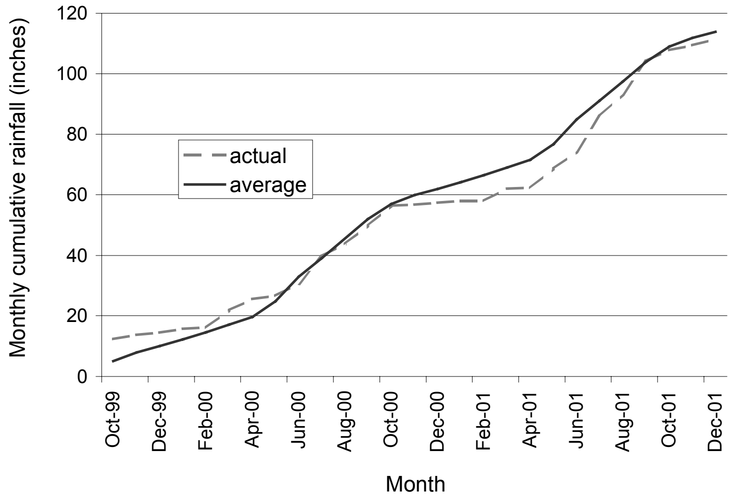

Figure 2-25. Water Conservation Areas 1 and 2 rain areas' actual and average cumulative rainfall

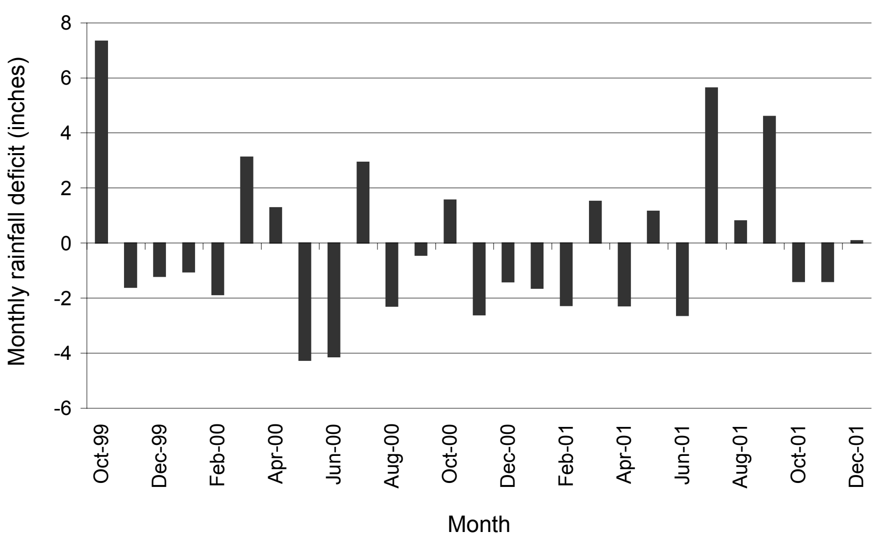

Figure 2-26. Water Conservation Areas 1 and 2 rain areas' monthly rainfall deficit

In general, monthly rainfall was below mean values for most of 2000 and 2001; the beginning of the drought can be traced back to November 1999. **Figures 2-27** and **2-28** show the dry season and wet season rainfall amounts for each rain area, respectively. The dry season extends from November through May. The wet season runs from June to October. Rainfall during the dry season was below expected values in 2000 and 2001. During the 2000 wet season, rainfall was below expected amounts for all rain areas, except Miami-Dade.

Table 2-2 depicts the return period in years associated with monthly rainfall amounts for each rain area. White squares indicate a month where rainfall was greater than expected (labeled with a "W"). Black and gray squares indicate dry months. The black squares show exceptionally dry months, where the rainfall amount had a return period of greater than 10 years (or the amount had a 10-percent chance or less of occurring). Of the 36 months examined, most rain areas experienced 10 to 14 wet months and 22 to 26 dry months. The West Ag rain area, however, had only eight wet months during a three-year period from 1999 to 2001. In contrast, WCAs 1 and 2 had 16 wet months. The Lower Kissimmee rain area had nine exceptionally dry months during this period. The Upper Kissimmee rain area had four exceptionally dry months and a total of 24 dry months, and the Lake Okeechobee rain area had three extremely dry months, with a total of 24 dry months

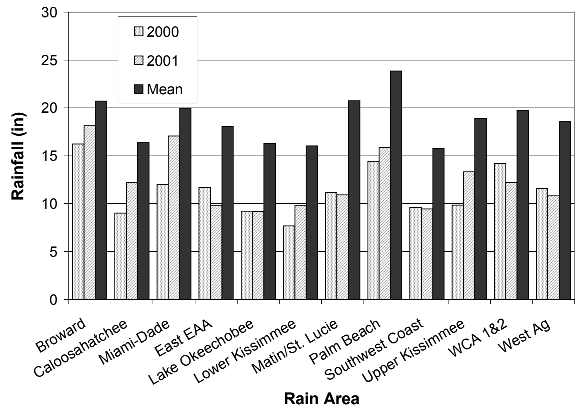

Figure 2-27. Dry season observed rainfall versus expected rainfall by rain area, 2000–2001

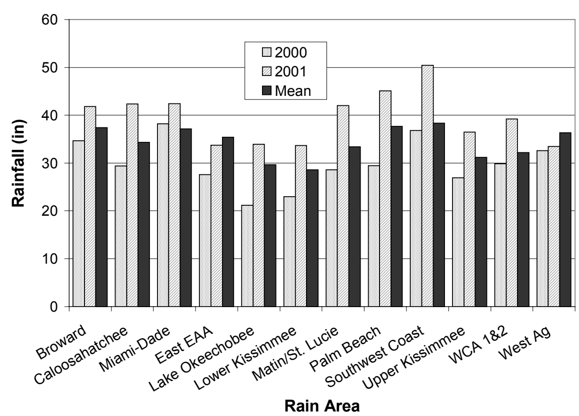

Figure 2-28. Wet season observed rainfall versus expected rainfall by rain area, 1999–2001

Table 2-2. Return period (years) of monthly rainfall observed during 1999-2001 by rain area

Month	Broward	Caloosahatchee	Miami-Dade	East EAA	Lake Okeechobee	Lower Kissimmee	Matin/St. Lucie	Palm Beach	Southwest Coast	Upper Kissimmee	WCA 1&2	West Ag
JAN-99 T_R	W 5-10	W 5-10	W 5-10	W 2-5	W 2-5	W 2-5	W 2-5	W 10-20	W 2-5	W 2-5	W 2-5	2-5
FEB-99 T_R	5-10	20-50	10-20	5-10	5-10	50-100	5-10	5-10	2-5	2-5	W 2-5	5-10
MAR-99 T_R	5-10	5-10	5-10	10-20	5-10	10-20	10-20	10-20	2-5	5-10	10-20	10-20
APR-99 T_R	2-5	2-5	2-5	2-5	W 2-5	W 2-5	2-5	2-5	2-5	2-5	2-5	5-10
MAY-99 T_R	2-5	2-5	2-5	2-5	2-5	2-5	2-5	5-10	2-5	W 2-5	2-5	W 2-5
JUN-99 T_R	W 20-50	W 10-20	W 5-10	W 5-10	W 10-20	W 10-20	W 5-10	W 10-20	W 2-5	W 5-10	W 20-50	W 5-10
JUL-99 T_R	5-10	2-5	2-5	2-5	2-5	10-20	5-10	5-10	2-5	>100	10-20	2-5
AUG-99 T_R	W 10-20	W 5-10	W 5	5-10	W 2-5	W 5-10	W 5-10	W 5	W 2-5	W 2-5	W 2-5	W 2-5
SEP-99 T_R	W 2-5	W 5-10	2-5	W 2-5	W 2-5	W 5-10	2-5	2-5	W 2-5	W 2-5	W 2-5	W 10-20
OCT-99 T_R	W 10-20	W 2-5	W 5-10	W 5-10	W 2-5	W 10-20	W 5-10	W 10-20	2-5	W 5-10	W 10-20	W 5-10
NOV-99 T_R	2-5	2-5	2-5	2-5	2-5	2-5	5-10	5-10	W 5-10	W 2-5	2-5	2-5
DEC-99 T_R	2-5	2-5	2-5	2-5	2-5	W 2-5	2-5	2-5	2-5	W 2-5	2-5	2-5
JAN-00 T_R	2-5	2-5	5-10	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5
FEB-00 T_R	2-5	5-10	2-5	2-5	2-5	>100	2-5	5-10	10-20	20-50	5-10	2-5
MAR-00 T_R	W 5-10	2-5	2-5	2-5	2-5	2-5	2-5	W 2-5	2-5	5-10	W 10-20	2-5
APR-00 T_R	2-5	2-5	W 2-5	W 5-10	W 2-5	2-5	W 2-5	W 2-5	2-5	2-5	W 2-5	10
MAY-00 T_R	2-5	5-10	5-10	10-20	20-50	50-100	>100	20-50	5-10	10-20	20-50	10-20
JUN-00 T_R	2-5	2-5	2-5	5-10	2-5	5-10	2-5	5-10	2-5	2-5	5-10	2-5
JUL-00 T_R	W 2-5	2-5	W 2-5	2-5	2-5	W 2-5	W 5-10	W 2-5	2-5	W 2-5	W 5-10	2-5
AUG-00 T_R	2-5	5-10	W 2-5	50-100	20-50	10-20	2-5	2-5	2-5	2-5	5-10	5-10
SEP-00 T_R	2-5	W 2-5	2-5	2-5	W 2-5	W 2-5	2-5	2-5	W 2-5	2-5	2-5	2-5
OCT-00 T_R	W 2-5	2-5	W 5-10	W 2-5	2-5	5-10	2-5	2-5	2-5	5-10	W 2-5	W 10-20
NOV-00 T_R	10-20	5-10	10-20	10-20	5-10	10-20	10-20	2-5	10	2-5	10-20	10-20
DEC-00 T_R	W 2-5	2-5	W 10-20	5-10	5-10	2-5	2-5	2-5	2-5	2-5	2-5	2-5
JAN-01 T_R	5-10	2-5	5-10	2-5	2-5	5-10	5-10	5-10	2-5	5-10	5-10	5-10
FEB-01 T_R	5-10	>100	20-50	>100	>100	>100	>100	50	20-50	20-50	50-100	>100
MAR-01 T_R	W 10-20	W 5-10	W 5-10	W 5-10	W 2-5	W 5-10	W 2-5	W 5-10	W 5-10	W 5-10	W 5-10	W 2-5
APR-01 T_R	2-5	10-20	2-5	20-50	5-10	10-20	5-10	10-20	2-5	5-10	10-20	>100
MAY-01 T_R	W 2-5	W 2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	W 2-5	W 2-5	W 2-5
JUN-01 T_R	2-5	2-5	2-5	2-5	2-5	2-5	W 2-5	2-5	2-5	2-5	2-5	2-5
JUL-01 T_R	W 2-5	W 20-50	W 2-5	W 2-5	W 10-20	W 5-10	W 20-50	W 5-10	W 20-50	W 2-5	W 20-50	2-5
AUG-01 T_R	2-5	W 2-5	2-5	2-5	2-5	2-5	W 2-5	W 2-5	2-5	2-5	W 2-5	5-10
SEP-01 T_R	W 10-20	W 5-10	W 5-10	W 5-10	W 5-10	W 50-100	W 2-5	W 10-20	W 20-50	W 10-20	W 10-20	W 10-20
OCT-01 T_R	2-5	2-5	W 2-5	2-5	W 2-5	W 2-5	2-5	2-5	2-5	2-5	2-5	2-5
NOV-01 T_R	2-5	2-5	2-5	2-5	2-5	2-5	W 2-5	2-5	2-5	2-5	2-5	2-5
DEC-01 T_R	2-5	2-5	W 2-5	W 2-5	2-5	2-5	2-5	W 2-5	W 2-5	2-5	W 2-5	2-5
# Dry Months	23	25	22	26	24	23	24	24	26	24	20	28
# Extreme Dry	1	3	3	6	3	9	4	4	2	4	6	6
# Wet Months	13	11	14	10	12	13	12	12	10	12	16	8

T_R exceptionally dry months T_R dry months   W T_R wet months

INFLOWS AND OUTFLOWS FROM MAJOR HYDROLOGIC COMPONENTS

The main storage component in the hydrologic system is Lake Okeechobee. Inflows come from the Upper and Lower Kissimmee watersheds, the Nubbin Slough and Taylor Creek basins, the Lake Istokpoga Water Management Area, Fisheating Creek, the Caloosahatchee Canal, the St. Lucie Canal, the Everglades Agricultural Area, and other smaller drainage basins. The main storage in the Upper Kissimmee Basin is Lake Kissimmee, with 55.5 square miles area and a watershed of 269.1 square miles (Ali, 1998).

LAKE KISSIMMEE FLOWS

Lake Kissimmee outflow is regulated through structure S65. The lake's regulation schedule varies from 49.25 ft NGVD in spring to 52.5 ft NGVD in winter. Flow data for discharge from Lake Kissimmee into the Kissimmee River (C-38 Canal) are available since 1934 (**Figure 2A-1-13**). Based on flow data from January 1, 1972 to September 30, 2001, the average annual outflow from Lake Kissimmee was 645,000 ac-ft, with standard deviation of 363,000 ac-ft. The maximum discharge of 1,460,000 ac-ft occurred during the 1995 El Niño year. The minimum annual flow of 7,900 ac-ft occurred during the 1981 drought. Flows during the 2000-2001 drought months are shown in **Table 2-3**. There were eight consecutive months with no outflow from Lake Kissimmee (November 2000 to June 2001). The total outflow from October 1999 through September 2001 was 701,490 ac-ft, of which 11,780 ac-ft was for the 12 months of July 2000 through June 2001. This is the third-lowest discharge volume for 12 consecutive months, with the record-lowest occurring during the 1971-1972 drought and the second-lowest occurring during the 1980-1982 drought.

LAKE ISTOKPOGA FLOWS

Lake Istokpoga outflow is regulated through structure S-68. The lake's regulation schedule varies between 37.5 ft NGVD and 39.5 ft NGVD. Historical annual flow data is depicted in **Figure 2A-1-14**. Based on flow data from January 1, 1972 to September 30, 2001, the average annual outflow from Lake Istokpoga was 192,000 ac-ft, with standard deviation of 125,000 ac-ft. The maximum discharge of 562,000 ac-ft occurred during the 1998 El Niño year. The minimum annual flow of 18,000 ac-ft occurred during the 1981 drought. Flows during the current drought months are shown in **Table 2-3**. The total outflow from October 1999 through September 2001 was 292,085 ac-ft, of which 23,813 ac-ft was for the 12 months of July 2000 through June 2001. The second-lowest annual discharge volume of 32,175 ac-ft occurred during the current drought in 2000.

Table 2-3. Flows of Lake Istokpoga, Lake Kissimmee, and Lake Okeechobee during the 2000-2001 drought (ac-ft)

		Lake Kissimmee	Lake Istokpoga	Lake Okeechobee								
Year	Month	outflow (S65)	outflow (S68)	inflow from North	total backflow	total inflow	outflow to South	outflow to North	outflow to East	outflow to West	total outflow	forward pumping
1999	October	182,244	64,827	566,384	53,958	620,322	11,681	0	40,991	124,227	176,889	0
1999	November	31,803	23,077	99,543	6,346	105,889	31,388	18	89,323	214,341	335,070	0
1999	December	47,291	11,355	66,850	2,369	69,219	86,553	18	53,007	100,643	240,221	0
2000	January	70,216	9,642	79,738	1,343	81,080	89,925	14	25,661	47,033	162,632	0
2000	February	74,478	5,059	72,383	1,082	73,465	28,535	14	9,650	8,864	47,063	0
2000	March	41,899	4,483	22,427	2,438	24,865	75,168	2621	5,161	29,207	112,157	0
2000	April	89,146	3,252	86,913	25,460	112,373	82,047	3981	38,754	88,476	213,258	0
2000	May	1,063	5,352	2,522	8,323	10,845	212,275	6997	107,698	200,308	527,278	0
2000	June	3,404	3,521	1,800	23,942	25,742	119,972	5079	2,254	26,922	154,228	0
2000	July	0	566	23,705	26,167	49,872	1,666	1303	13,912	1,206	18,087	0
2000	August	0	0	23,159	14,257	37,416	22,826	3296	15,317	18,456	59,895	0
2000	Septembr	5,234	2	63,865	58,812	122,677	9,116	790	6,016	2,535	18,459	0
2000	October	6,494	0	30,981	89,795	120,775	6,178	2443	1,785	10,818	21,225	0
2000	November	0	0	465	9,399	9,865	41,311	6607	17,978	26,512	92,409	0
2000	December	0	297	15	5,736	5,750	36,351	1601	5,064	17,189	60,205	0
2001	January	0	0	97	6,863	6,959	17,710	1081	4,864	1,220	24,847	0
2001	February	0	20,301	114	985	1,099	22,984	253	6,985	6,976	37,197	0
2001	March	0	1,526	567	11,691	12,258	27,129	1485	9,657	7,457	45,728	442
2001	April	0	1,119	1,337	3,981	5,317	46,755	2154	2,707	23,790	75,406	41,261
2001	May	0	0	34	11,603	11,637	51,599	1077	806	9,965	63,407	50,058
2001	June	0	0	8,871	77,732	86,603	1,116	0	422	0	1,538	905
2001	July	4,861	1,578	177,773	184,272	362,045	463	0	0	224	687	238
2001	August	50,099	27,794	250,693	209,887	460,579	1,533	0	254	75	1,862	0
2001	Septembr	93,258	108,334	525,120	172,144	697,264	785	1	904	0	1,691	0
Total		**701,490**	**292,085**	**2,105,356**	**1,008,585**	**3,113,916**	**1,025,066**	**40,833**	**459,170**	**966,444**	**2,491,439**	**92,904**

LAKE OKEECHOBEE FLOWS

Based on flow data from January 1, 1972 to September 30, 2001, major surface inflows are from the Upper and Lower Kissimmee watersheds through structure S-65E (47.5 percent), the Lake Istokpoga Water Management Area (9.1 percent), and Fisheating Creek (8.6 percent). Reverse flows are from the Everglades Agricultural Area, the Caloosahatchee and St. Lucie canals (16.8 percent), and 18 percent from other structures around the lake. Inflow is from the north and northwest, and reverse inflow is from the south, southwest, and southeast. The average total annual inflow of surface water was 1,999,000 ac-ft, with an annual maximum of 3,520,000 ac-ft during the 1995 El Niño, minimum of 675,000 ac-ft during the 2000 drought and a standard deviation of 834,000 ac-ft. Average annual reverse inflow from the EAA, the Caloosahatchee Canal and the St. Lucie Canal was 333,000 ac-ft, with a standard deviation of 146,000 ac-ft. **Figure 2-29** depicts historical inflow and outflow from Lake Okeechobee indicating drought years. **Figure 2-30** depicts mean monthly historical inflows and outflows.

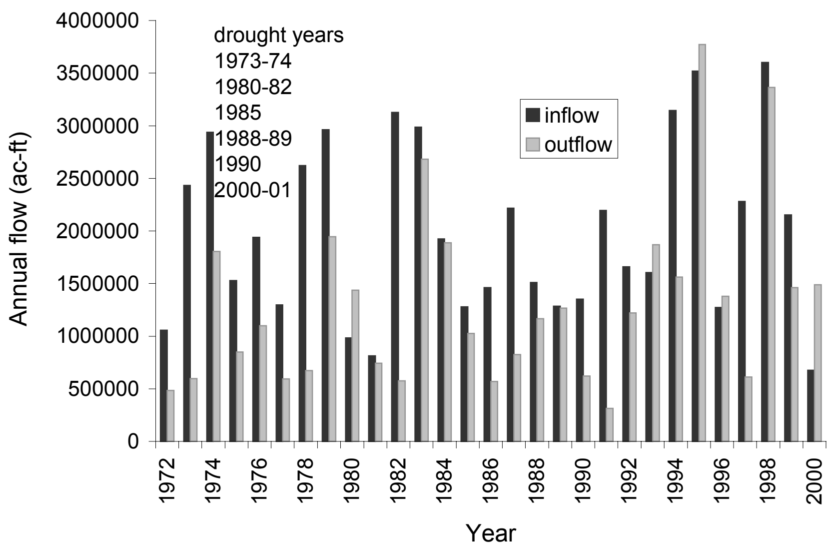

Figure 2-29. Historical inflows and outflows for Lake Okeechobee

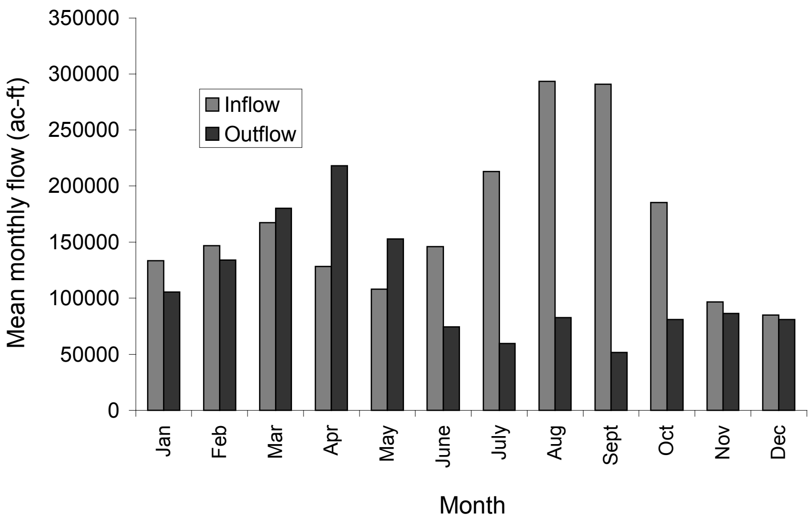

Figure 2-30. Monthly average inflows and outflows for Lake Okeechobee, January 1972-2001

The drought's effect on Lake Okeechobee inflows and outflows is significant. From December 1999 to June 2001 there were 19 consecutive monthly inflows below the historical average (**Table 2-3** and **Figure 2-31**). The significant increase in lake inflow from July to September 2001 is apparent and corresponds with an increase in rainfall and a decrease in drought effect. Through the same period, backflow into the lake through pumping and gravity was 32 percent (**Table 2-3**), and the remaining inflow of 68 percent was from the north. Historical backflows to Lake Okeechobee from the south, southeast, and southwest are depicted in **Figure 2-32**. The maximum annual backflow occurred in the nine months of 2001 (679,157 ac-ft). The total backflow to the lake for the period October, 1999 to September 2001 was 1,017,224 ac-ft of which 420,701 was back pumping through S-2 and S-3 pump stations. **Table 2-4** depicts monthly back pumping and backflow into Lake Okeechobee.

Table 2-4. Back pumping and backflow to Lake Okeechobee (ac-ft)

		S3	S2	S352	S308	S77	L8	Indust.	S4	C10	C12	C12A	C4A	S236
		backpump	backpump	backflow	backflow	backflow	backflow	backflow	backpump	to Lake	to Lake	to Lake	to Lake	to Lake
		ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft	ac-ft
Year	Month													
1999	October	2821	28973	0	0	0	0	0	6578	6354	4177	4617	1752	2713
1999	November	0	0	0	0	0	0	0	1572	657	597	2201	254	613
1999	December	147	0	0	0	0	0	0	196	0	0	1068	0	420
2000	January	0	0	0	0	0	0	0	0	376	0	687	0	309
2000	February	0	139	0	0	0	0	0	0	365	0	502	0	188
2000	March	0	301	0	0	0	54	0	0	486	569	977	44	0
2000	April	1188	5889	0	0	0	4729	4250	2795	2077	1652	1668	602	1845
2000	May	0	0	0	7323	0	1000	0	0	0	0	0	0	0
2000	June	131	0	0	17324	0	3033	2805	0	0	155	43	0	431
2000	July	167	0	0	14551	0	4619	1352	0	652	1044	1575	280	1785
2000	August	0	194	0	2251	0	9220	258	0	298	354	859	605	83
2000	September	446	772	0	37617	0	5806	6183	288	2227	2276	1859	1109	1519
2000	October	7045	24913	105	14320	0	34836	2713	199	1834	2088	1405	516	945
2000	November	0	145	0	0	0	9139	28	88	0	0	0	0	0
2000	December	0	0	0	325	2055	3106	139	74	0	0	24	0	0
2001	January	0	194	0	0	5818	576	275	0	0	0	0	0	0
2001	February	0	0	0	0	0	464	156	0	0	0	243	0	0
2001	March	3171	5216	0	815	113	800	312	0	215	381	318	404	0
2001	April	637	731	0	647	1079	725	30	0	0	0	53	53	0
2001	May	145	0	0	3973	7450	0	35	0	0	0	0	0	0
2001	June	7587	16150	0	14781	37179	0	1158	0	0	0	218	218	332
2001	July	39414	64004	0	30518	29237	14710	1806	0	337	669	970	622	1834
2001	August	39523	75964	0	29150	4596	38422	2638	10001	1635	2536	1755	428	3989
2001	September	46477	48219	0	22721	0	34680	7699	4100	2320	1867	1163	1156	3475
Total		**148899**	**271802**	**105**	**196316**	**87526**	**165917**	**31836**	**25891**	**19835**	**18365**	**22205**	**8045**	**20481**

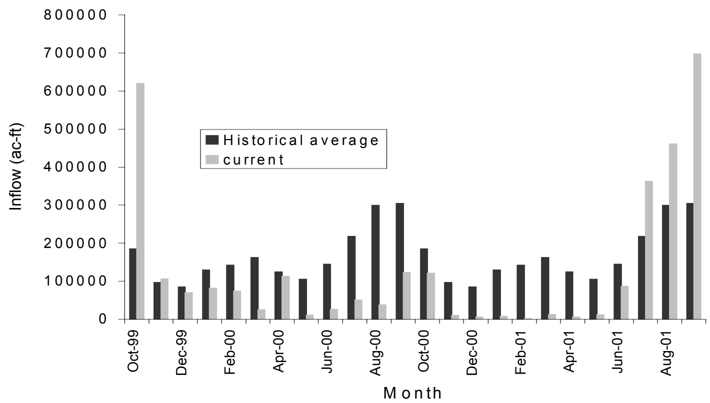

Figure 2-31. Comparison of historical average and current Lake Okeechobee monthly inflows

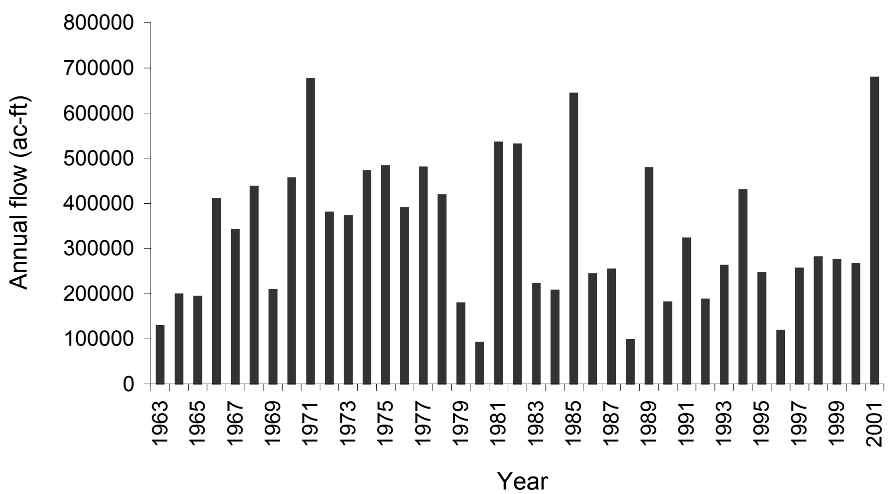

Figure 2-32. Annual backflow to Lake Okeechobee through pumping and gravity (nine months for 2001)

Outflows are mainly through the south, southeast, and southwest structures. The average historical (1972 to 2001) annual outflow was 1,282,000 ac-ft, with a standard deviation of 838,000 ac-ft; maximum annual outflow was 3,771,000 ac-ft during the 1995 El Niño, and minimum was 314,115 ac-ft in 1991. Monthly mean historical inflows and outflows are depicted in **Figure 2-30**. Comparison of monthly Lake Okeechobee outflows to the historical average is shown in **Figure 2-33**. A significant portion of the discharge during the managed lake recession is shown in May 2000 flows. For the period from October 1999 to September 2001, 16 months of outflows from the lake were below the historical average. **Table 2-3** shows a breakdown of monthly outflows to the east through S-308 (18 percent); to the north through G-207 and G-208 (2 percent); to the west through S-77 (39 percent), and to the south through the EAA structures (41 percent). When the lake stage reached 10.1 ft NGVD, temporary forward pumps were activated at the S-351, S-352, and S-354 structures to discharge water to the south (**Table 2-3**). The pumps were operated irregularly from March 28, 2001 to July 3, 2001, for a total discharge of 92,904 ac-ft.

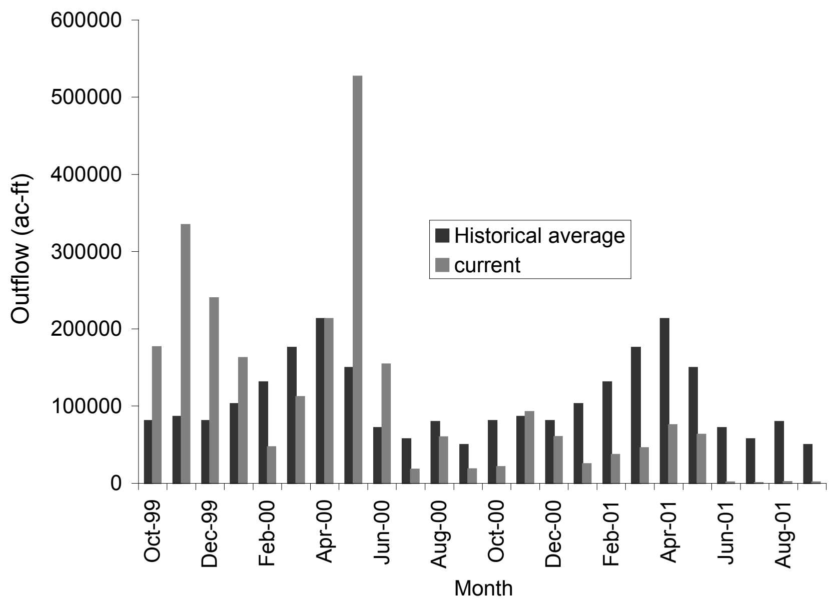

Figure 2-33. Comparison of historical average and current Lake Okeechobee monthly outflows

INFLOWS AND OUTFLOWS FOR STORMWATER TREATMENT AREAS

In general, monthly inflows and outflows to Stormwater Treatment Areas (STAs), located in the Everglades Agricultural Area (EAA), were reduced due to the drought. Monthly inflow and outflow at STA-1W, STA-5 and STA-6 are shown, respectively, in **Figures 2-34**, **2-35**, and **2-36**. The monthly summary of flow through each structure is shown in **Tables 2A-2-1**, **2A-2-2**, and **2A-2-3**. Efforts were made to prevent treatment cell dry-out at STA-1W and STA-5. During the most severe period of the drought, December 2000 through May 2001, both STA-5 and STA-6 dried out. This was typical during the dry season for STA-6, but a temporary pump was located at STA-5 to keep Cell 1-B wet to help maintain the submerged aquatic vegetation (SAV) that had been introduced into the cell after STA start-up in 1999-2000. STA-1W received 295,162 ac-ft of inflow from October 1999 through September 2001, and 321,344 ac-ft were discharged during the same period. Inflow to STA-5 was 166,701 ac-ft and outflow was 158,693 ac-ft. STA-6 received 89,079 ac-ft and discharged 64,877 ac-ft of water during the same 24-month period. All the STAs began to receive significant inflow beginning in June and July 2001, which aided in their recovery from the drought.

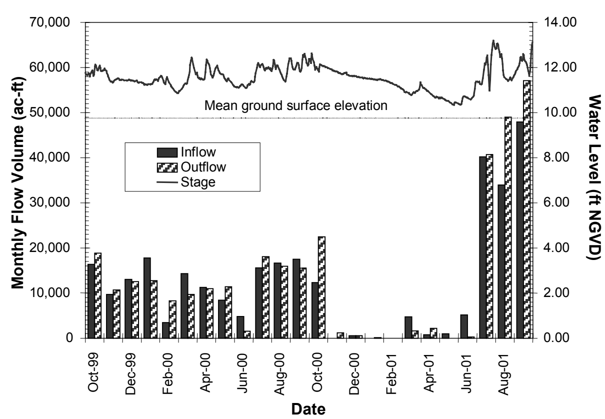

Figure 2-34. STA-1W inflow, outflow, and water level

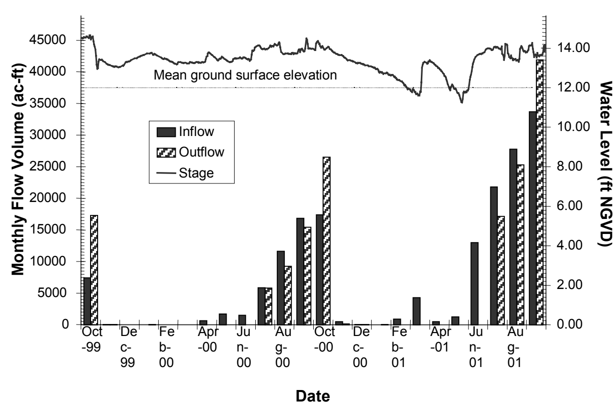

Figure 2-35. STA-5 inflow, outflow, and water level

INFLOWS AND OUTFLOWS TO THE WATER CONSERVATION AREAS

Inflows to the Loxahatchee National Wildlife Refuge (Water Conservation Area 1), WCA 2, and WCA-3 began to decline beginning in October 1999 after the passage of Hurricane Irene. There was a brief recovery in April of 2000 and again in September and October 2000 as tropical weather systems brought increased rainfall. Significant inflows to all the WCAs began again in July 2001 and led to recovery of water levels in all the WCAs by the end of September 2001. The ability to release water from the WCAs for water supply purposes was severely restricted during 2001. Inflow and outflow volumes for Water Conservation Area 1 were 841,576 ac-ft and 885,941 ac-ft, respectively, for the period from October 1999 through September 2001. Inflow and outflow volumes for Water Conservation Area 2 were 915,197 ac-ft and 884,803 ac-ft, respectively, for the same period. Inflow and outflow volumes for Water Conservation Area 3 were 1,323,856 ac-ft and 1,706,935 ac-ft, respectively, for the same period. **Figures 2-37**, **2-38**, and **2-39** show the monthly inflow and outflow volumes for each WCA. Monthly summary of flow through each structure is shown in **Tables 2A-2-4**, **2A-2-5**, and **2A-2-6**.

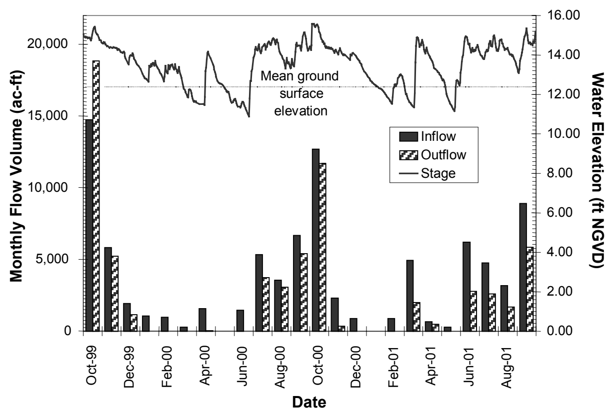

Figure 2-36. STA-6 inflow, outflow, and water level

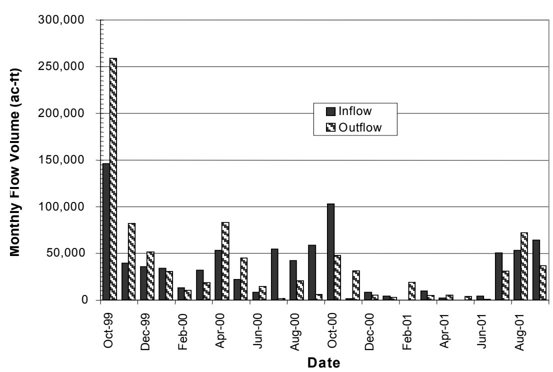

Figure 2-37. Loxahatchee National Wildlife Refuge (Water Conservation Area 1) inflow and outflow

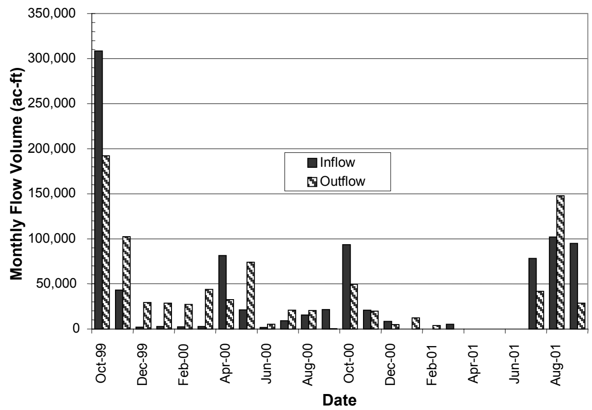

Figure 2-38. Water Conservation Area 2 inflow and outflow

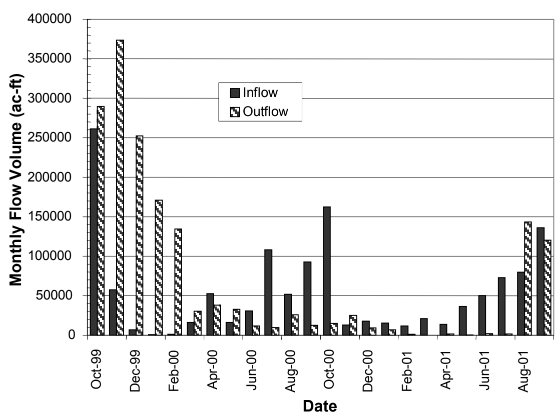

Figure 2-39. Water Conservation Area 3 inflow and outflow

COASTAL OUTFLOWS

Monthly flow volumes at SFWMD coastal structures are summarized by service area in **Figure 2-40**. **Table 2-5** shows the total flow volume discharged to tide for the 24-month period. Two periods of high flow are shown, the first being associated with flow from Hurricane Irene, and the second, which affected the Miami-Dade area (Lower East Coast, Service Area 3), was caused by an un-named tropical depression. Releases to tide were negligible during the height of the drought in the first several months of 2001. A monthly summary of flow through each structure is shown in **Table 2A-2-7**.

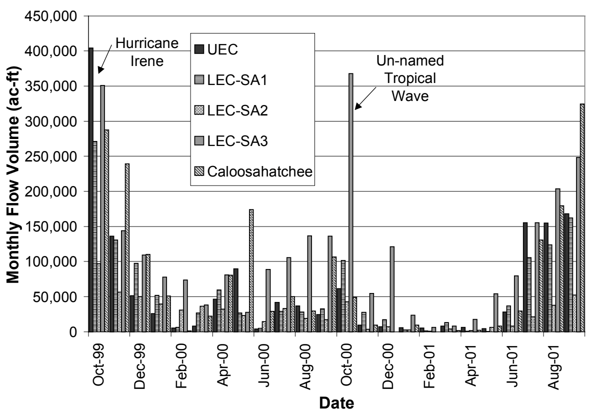

Figure 2-40. Monthly coastal outflow volumes by service area, 1999-2000

Area	Volume (ac-ft)
UEC	1,489,148
LEC-SA1	1,357,643
LEC-SA2	636,185
LEC-SA3	2,709,720
Caloosahatchee	1,924,825
Total	8,117,521

Table 2-5. Coastal structure monthly outflow volume, 1999-2001

INFLOWS TO THE EVERGLADES NATIONAL PARK

Figure 2-41 depicts monthly inflow volumes to Everglades National Park (ENP) from October 1999 to September 2001. The monthly flow pattern corresponds to flows in Water Conservation Area 3. Inflow was minimal from January 2001 through June 2001 and increased starting in August 2001. Total inflow for the 24-month period was 2,555,198 ac-ft. Monthly summary of flow through each structure is shown in **Table 2A-2-8**.

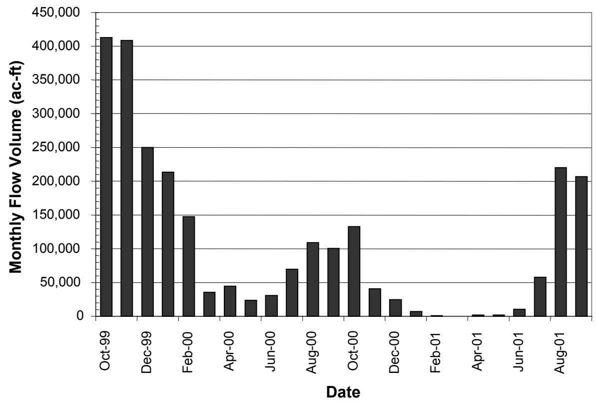

Figure 2-41. Everglades National Park inflow

DYNAMICS IN SYSTEM STORAGE AND HYDROLOGIC SUMMARY

System storage was reported daily. The main components of storage in the SFWMD system are Lake Okeechobee and Water Conservation Areas 1, 2, and 3. Total available system storage for Lake Okeechobee peaked in November 1999 and began to recede through June 2001 to exceptionally low levels due to releases and evaporation losses. As the system approached zero gravitationally available storage in May 2001, temporary forward pumps were placed at the S-351, S-352, and S-354 structures for water supply. The forward pumping effectively added approximately 684,000 ac-ft of potential available storage, although a smaller volume was pumped out. Starting in June 2001 the system began a rapid recovery to near-average seasonal levels by the end of September 2001. **Figure 2-42** shows the trend in available storage for Lake Okeechobee from October 1999 to September 2001.

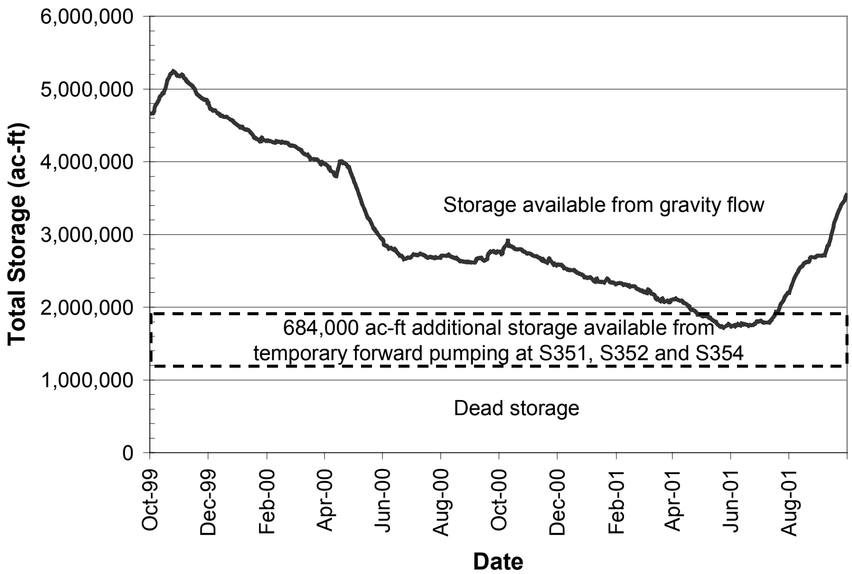

Figure 2-42. Lake Okeechobee available storage, October 1999 to September

WATER LEVELS

Water levels in lakes and reservoirs are gauges for drought and water shortage conditions. The major lakes and water holding areas (impoundments) in the South Florida Water Management District are Lake Okeechobee, Lake Istokpoga, Lake Kissimmee, Lake Myrtle, Alligator Lake, Lake Gentry, Lake Mary Jane, East Lake Tohopekaliga, Lake Tohopekaliga, and water conservation areas 1, 2, and 3. Water level data for Lake Okeechobee are available since 1931. **Figure 2-43** shows daily water levels for Lake Okeechobee, and reported drought years are marked. The minimum lake level for the period of record of 8.97 ft NGVD was reached on May 24, 2001. The maximum water level of 18.77 ft NGVD was achieved on November 2, 1947. The lake's water level was at or below 11 ft NGVD for 3 percent of days since 1931. **Figure 2-44** shows the number of consecutive days the lake was below 11.0 ft NGVD; the longest, 194 days, was achieved in 2001.

The consecutive number of days the lake stage has been below 11.00 ft NGVD matches the drought years. The mean lake stage and standard deviation at the beginning of each month are shown in **Figure 2-45**. A stage decline of two standard deviations from the mean can be taken as a measure of the criticality of Lake Okeechobee's storage decline. Also, the number of days below a given stage (e.g., 11 ft NGVD) can be used as a measure of the criticality of Lake Okeechobee's storage decline.

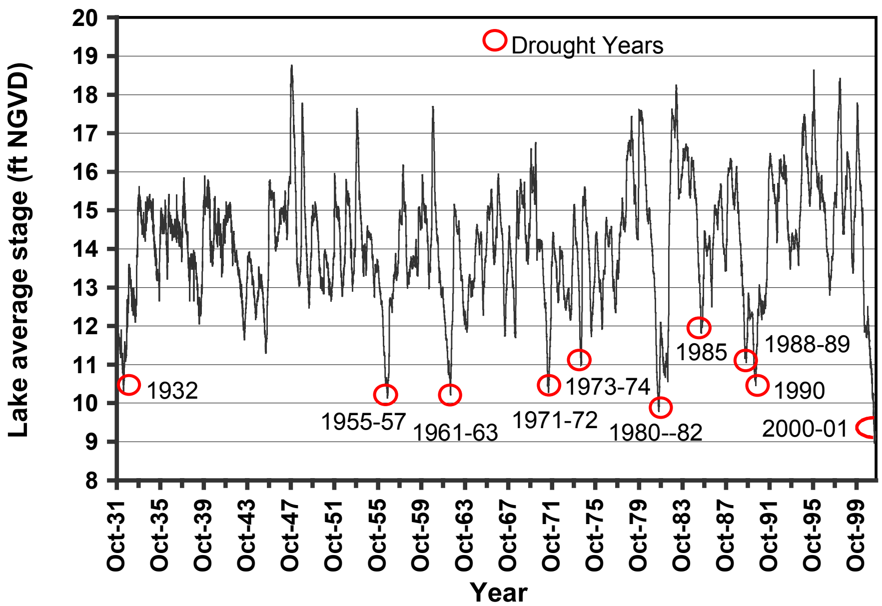

Figure 2-43. Average daily water level for Lake Okeechobee

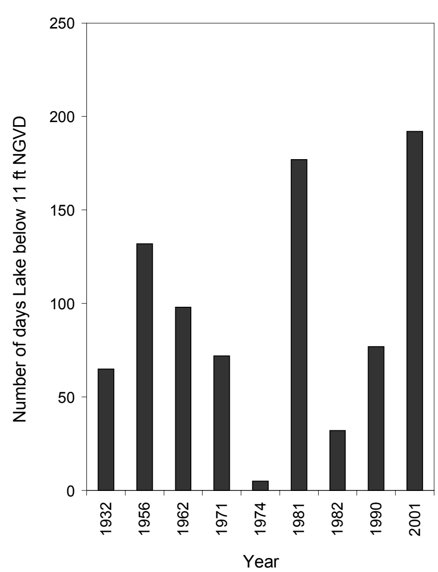

Figure 2-44. Number of days Lake Okeechobee water level was below 11 ft NGVD

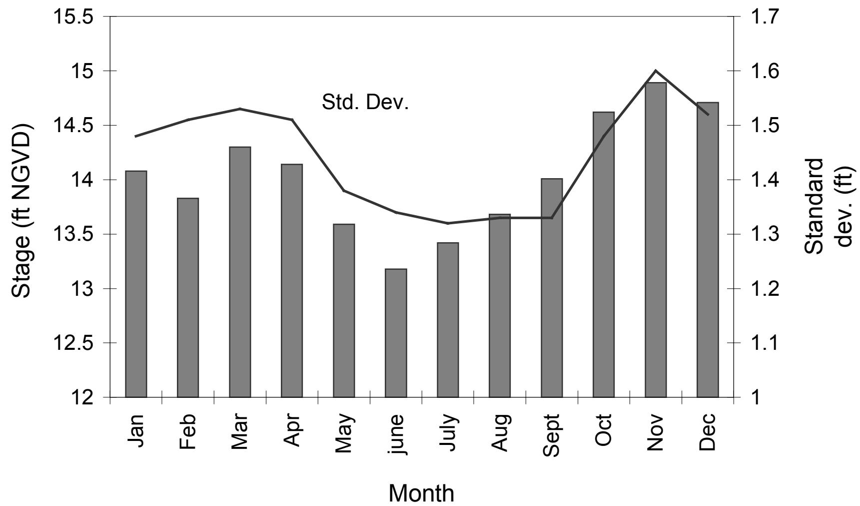

Figure 2-45. Mean lake water level and standard deviation for Lake Okeechobee at the beginning of each month

Lake Okeechobee's daily water level and evaporation losses are shown in **Figure 2-46**. The lake's water level declined from 16.53 NGVD on October 1, 1999 to 8.97 ft NGVD on May 24, 2001. The total decline was 7.56 ft. The evaporation loss for Lake Okeechobee for the period from October 1, 1999 to September 30, 2001 was 9.06 ft. Decreased inflow and rainfall increase in discharge and evaporation correspond to the lake's stage decline. Increased inflow from the north, backflow to the lake, and reduced discharge from the lake correspond to a gain in stage.

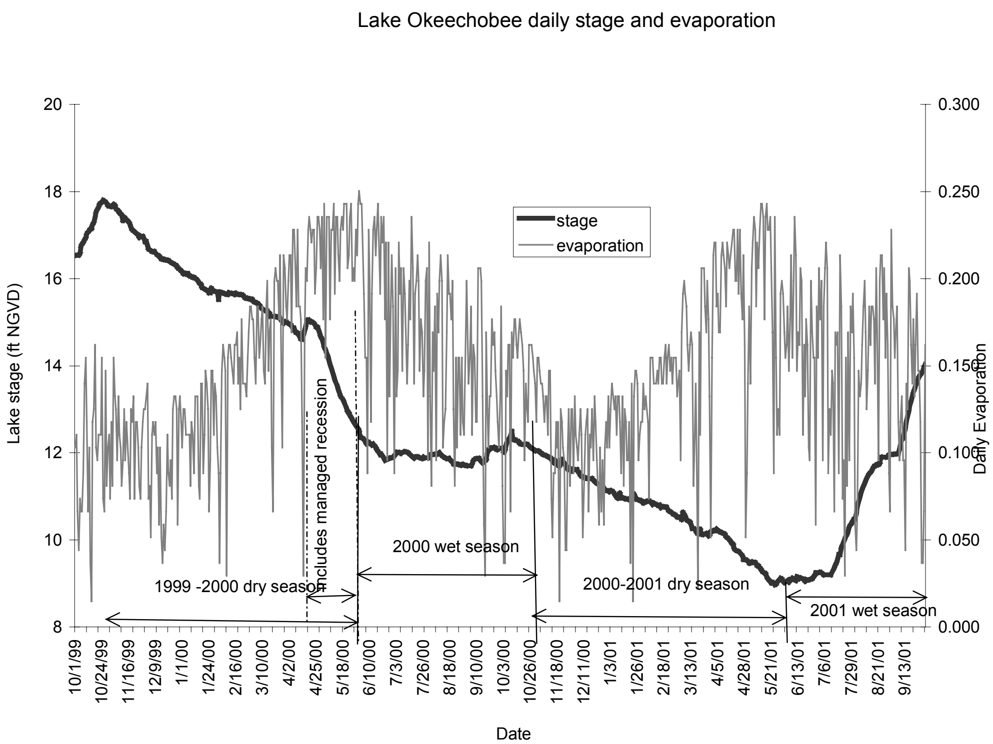

Figure 2-46. Lake Okeechobee daily water level and evaporation

Historical daily average water levels for Lake Kissimmee and Lake Istokpoga are shown in **Figures 2A-1-15** and **2A-1-16**. Lake Kissimmee, with an area of 35,520 acres, has been regulated by the S-65 structure since 1964 with in a little more than three feet fluctuation. Lake Kissimmee attained a maximum daily average water level of 56.64 ft NGVD on October 12, 1953 and a minimum of 42.87 ft NGVD on May 25, 1977. The historical average lake level is 50.38 ft NGVD. Lake Istokpoga, with an area of 28,160 acres, has been regulated by the S-68 structure since the early 1960s within three feet of fluctuation. Lake Istokpoga attained a maximum daily average water level of 42.9 ft NGVD on September 17, 1945 and a minimum of 35.4 ft NGVD on May 29, 1962. The historical average lake level is 38.59 ft NGVD. **Figure 2-47** depicts water level fluctuations of Lake Kissimmee and Lake Istokpoga from October 1, 1999 to September 30, 2001. Lake Kissimmee fluctuated between 52.57 and 48.28 ft NGVD, with the minimum level occurring on April 29, 2001. Lake Istokpoga fluctuated between 39.55 and 35.88 ft NGVD, with the minimum occurring on June 19, 2001.

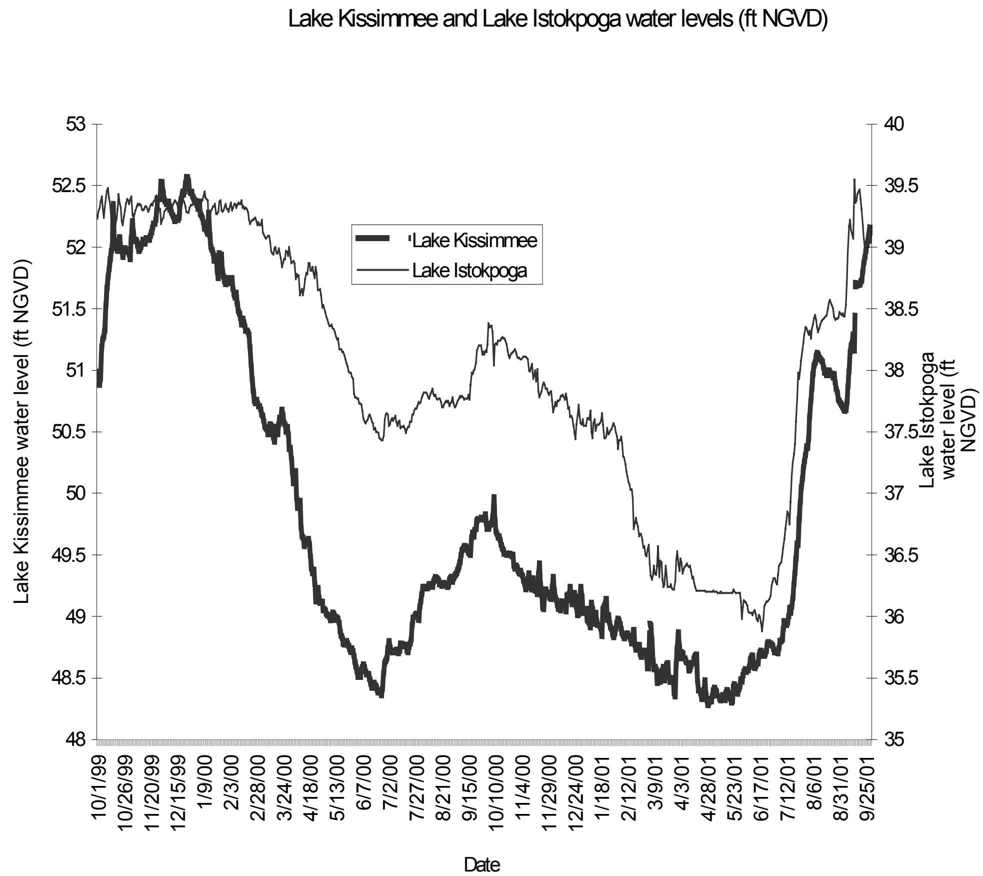

Figure 2-47. Lake Kissimmee and Lake Istokpoga daily water levels

The Water Conservation Areas are shallow impoundments, with a total area of approximately 736,640 acres. Water Conservation Area 1 (Loxahatchee National Wildlife Refuge) is 140,800 acres in area, with a daily average water level of 15.55 ft NGVD. The maximum daily average water level of 18.19 ft NGVD was attained on October 16, 1999, and the minimum level of 10 ft NGVD was reached on June 1, 1962. Average depth is 15.5 ft. Water Conservation Area 2A is 105,408 acres in area, with an average water level of 12.59 ft NGVD. The maximum water level of 15.64 ft NGVD was attained on November 18, 1969 and the minimum level of 9.33 ft NGVD was reached on April 29, 1989 during a drought year. Water Conservation Area 3A is 491,072 acres in area, with an average water level of 9.46 ft NGVD. The maximum water level of 12.79 ft NGVD was attained on January 22, 1995 during an El Niño year, and the minimum level of 4.78 ft NGVD was reached on June 19, 1962 during a drought year. Historical daily water levels for the water conservation areas are shown in **Figures 2A-1-17**, **2A-1-18**, and **2A-1-19**. Daily water level fluctuations for the three water conservation areas during the current drought period are shown in **Figure 2-48**.

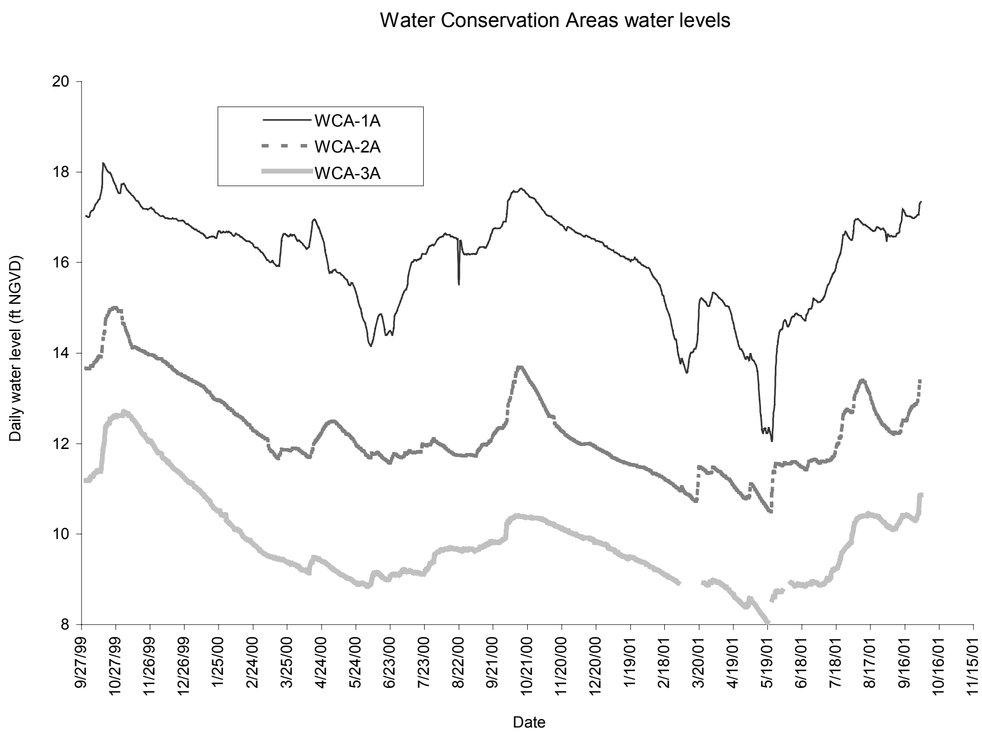

Figure 2-48. Water Conservation Areas' daily water levels

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Ali, A. and W. Abtew. 1999. Regional Rainfall Frequency Analysis for Central and South Florida. *Technical Publication. WRE # 380*, South Florida Water Management District, West Palm Beach, FL.

Burpee, R.W. and L.N. Lahiff. 1984. Area-average Rainfall Variation on Seabreeze Days in South Florida, *Monthly Weather Review*, Vol. 112:520-534.

Rosenthal, S.L. 1994. Statistical Aspects of the Precipitation Regimes at Miami International Airport (MIA) and Palm Beach International Airport (PBIA): 1961-1990. *NOAA Technical Memorandum ERL AAOML-80*.

Winsberg, M.D. 1990. *Florida Weather*. University of Central Florida Press, Orlando.

Chapter 3: Groundwater Responses to the Drought

Simon Sunderland

SUMMARY

This section provides a summary of groundwater levels in key aquifers around the District between October 1, 1999 and September 30, 2001. A District hydrogeologist reviewed water level data from a network of 81 real-time monitoring wells on a weekly basis during this period. **Figure 3-1** shows the layout of the real-time monitoring well network. This network was set up and is currently monitored under a cooperative agreement with the United States Geological Survey (USGS), Miami sub-district.

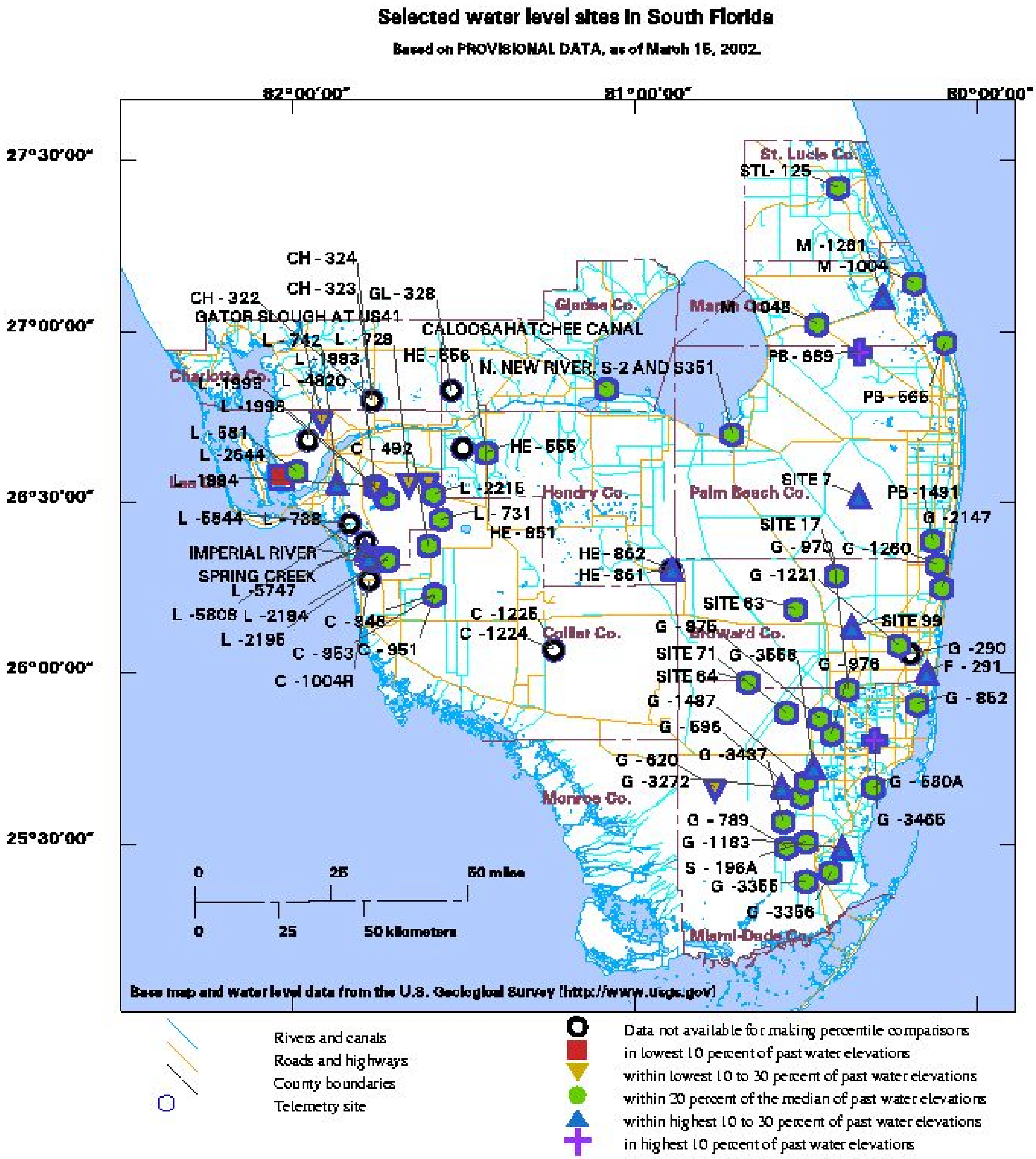

Figure 3-1. USGS real-time monitoring well network

This report contains several hydrographs that show water level trends in various aquifers around the District between October 1, 1999 and September 30, 2001. The hydrographs for monitoring wells in the Lower East Coast and Lower West Coast planning areas show water level trends and water levels estimated by statistical analysis. Data for these hydrographs were obtained from the USGS Statistical Overview of Selected USGS Water Level Monitoring Sites website. The hydrographs show the daily maximum water level elevation, as well as several statistical trends. The lowest colored line on each graph represents the first percentile of data, and represents a value below which only one percent of water level values for the well occurred. The line above that is the tenth percentile, below which ten percent of water levels occurred. Sequentially, above the tenth percentile are lines for the 30th percentile, median, 70th, 90th, and 99th percentiles, respectively, below which 30, 50, 70, 90, and 99 percent of water level values occurred. The 50th percentile represents an estimate of the mean water level for the well.

The average water level change per month in each aquifer around the District is shown in **Table 3-1**. This table indicates the average water level change in one month in each aquifer from November 2000 to September 2001.

Table 3-1. Average monthly water level changes by aquifer

Changes by Aquifer	Nov 00	Dec 00	Jan 01	Feb 01	Mar 01	Apr 01	May 01	Jun 01	Jul 01	Aug 01	Sep 01
LEC											
Biscayne in Broward	0.91	.03	0.60	0.68	.59	0.78	.06	0.16	.82	1.27	0.85
Biscayne in Dade	0.44	.13	0.48	0.53	0.39	1.06	.85	.15	.37	0.17	0.24
LWC											
Surficial	0.90	0.39	0.53	0.23	0.05	0.99	.04	.03	.58	0.90	0.51
Lower Tamiami	.47	.80	0.26	1.47	0.17	6.19	.46	.12	.21	1.37	1.17
Mid-Hawthorn	4.26	.82	.57	0.40	.40	.04	1.13	.65	.00	.24	2.96
Sandstone	4.01	3.48	.14	3.61	.71	5.99	.43	.11	.42	1.03	1.51
UEC											
Surficial	0.80	0.28	0.30	0.31	0.33	0.74	.13	.64	.67	0.67	0.59
Kissimmee Basin											
Floridan								.78	.64	0.56	2.59
Palm Beach County											
Surficial	1.00	.14	0.39	0.86	.74	0.92	0.12	.50	.73	1.60	1.05

KISSIMMEE BASIN

During the drought, the District reviewed only groundwater levels in the Floridan Aquifer in the Upper Kissimmee Basin in Orange County. This area was of interest to the District because it is adjacent to the city of Orlando, which is a major water user of the Floridan Aquifer. Land use in the Southern Kissimmee Basin is primarily agricultural, and water use demands are not as significant as those from the municipalities in the northern part of the region. Also, the District/USGS real-time monitoring well network does not extend into the southern portion of the Kissimmee Basin. Because of this, no water level data was available.

Upper Floridan Aquifer

The upper Floridan Aquifer in the Upper Kissimmee Basin consists of a thick series of carbonate rocks. Permeability in the aquifer is a result of fractures or solution cavities in the limestone that yield large quantities of water to wells (Shaw and Trost, 1984). The aquifer is the main source of potable water for the region.

Water level data for the upper Floridan Aquifer in this region were sparse because a substantial real-time monitoring-well network is not in place. Data retrieved from the USGS National Water Information System (NWIS) database does not yield continuous data, but rather monthly averaged values. Data between October 1, 1999 and September 30, 2001 was plotted on a hydrograph and is depicted in **Figure 3-2**. A District hydrogeologist calculated the average water level by month and included this trend on the hydrograph. The purpose of depicting the monthly average was to indicate how the drought affected the water level in the upper Floridan Aquifer relative to the normal water level in the aquifer. The location of the well used to show water level trends in the aquifer is shown in **Figure 3.3**.

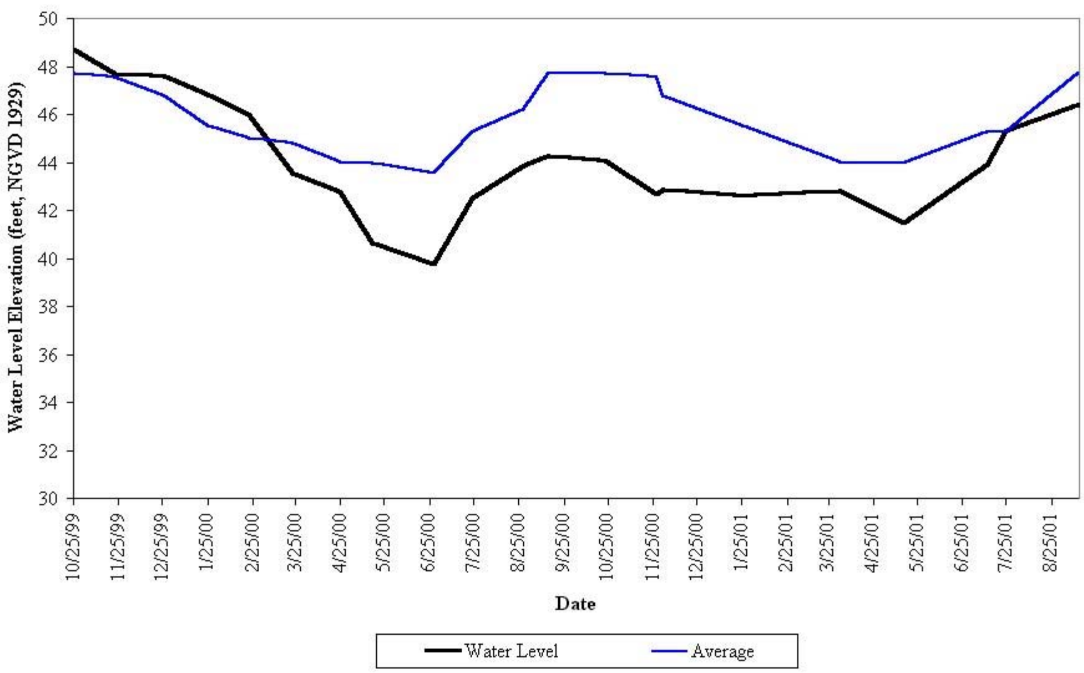

Figure 3-2. Hydrograph for the Boggy Creek Floridan Aquifer monitoring well, October 1, 1999 to September 30, 2001

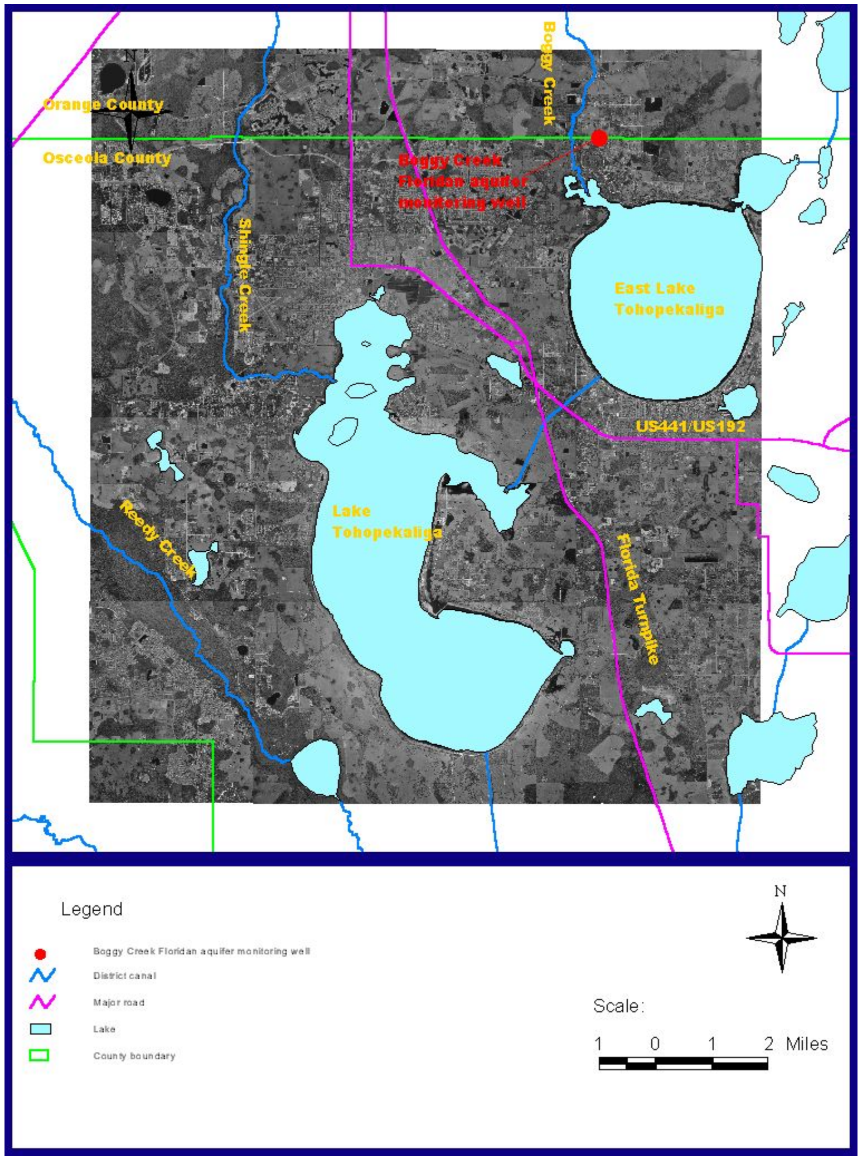

Figure 3-3. Location of the Boggy Creek Floridan Aquifer monitoring well

During the drought, the water level in the upper Floridan Aquifer dropped below its average level in mid-March 2000 and remained there through September 30, 2001. The water level in the aquifer briefly approached its normal level in late July 2001, but dropped below thereafter.

UPPER EAST COAST PLANNING AREA

Surficial Aquifer System

The Surficial Aquifer System (SAS) in the Upper East Coast (UEC) Planning Area is a shallow, unconfined aquifer. The SAS consists of unconsolidated fine-to-medium quartz sand, with inter-bedded layers of limestone, sandstone, shells, and clay. It is the sole source of potable water in the area (Lukasiewicz and Switanek, 1995). Between October 1, 1999 and September 30, 2001, water level trends in the aquifer were based on four real-time monitoring wells in the area (**Figure 3-1**).

During the drought, there were two distinct periods of low water levels in the SAS. One period occurred from early December 1999 through the end of October 2000. The other occurred between early November 2000 and early August 2001. Since the SAS is unconfined, it is principally recharged by rainfall. These periods of low groundwater levels occurred during periods of below-normal rainfall. **Figures 3-4** and **3-5** are hydrographs for monitoring wells STL-125 (St. Lucie County) and M-1004 (Martin County), respectively. In **Figure 3-5**, water level fluctuations during the drought are not as dramatic as those in **Figure 3-4** (STL-125). This phenomenon can be explained by the aquifer's lower permeability in the vicinity of M-1004. These wells are presented in this report because they are the best representatives of the aquifer's water level trends that resulted from the drought that occurred between October 1, 1999 and September 30, 2001.

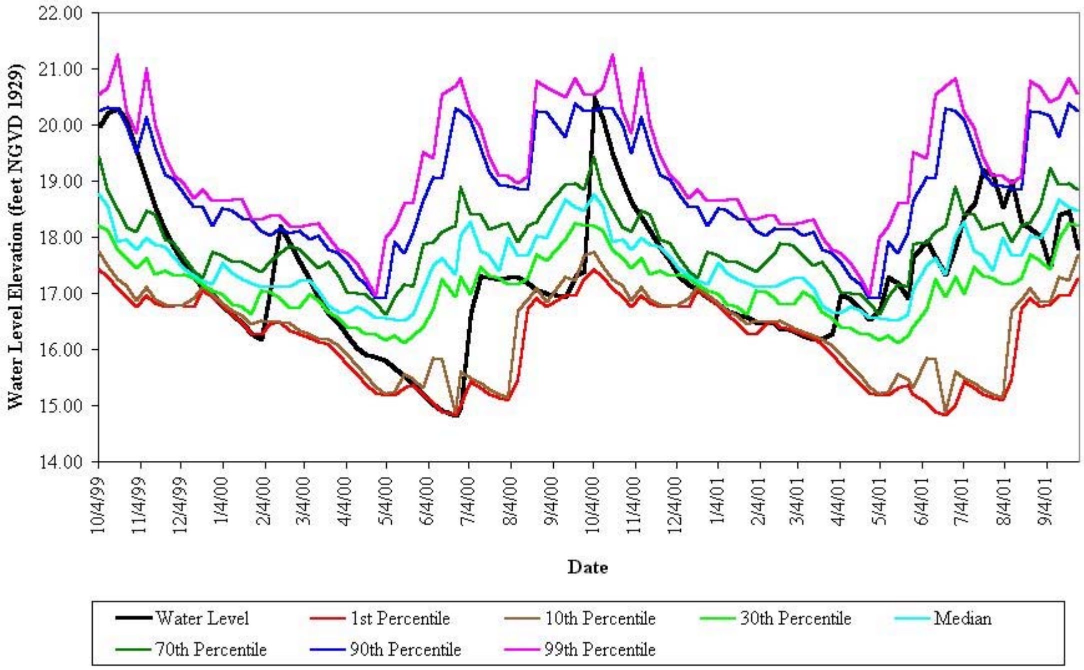

Figure 3-4. Hydrograph for STL-125 Surficial Aquifer monitoring well, October 1, 1999 to September 30, 2001

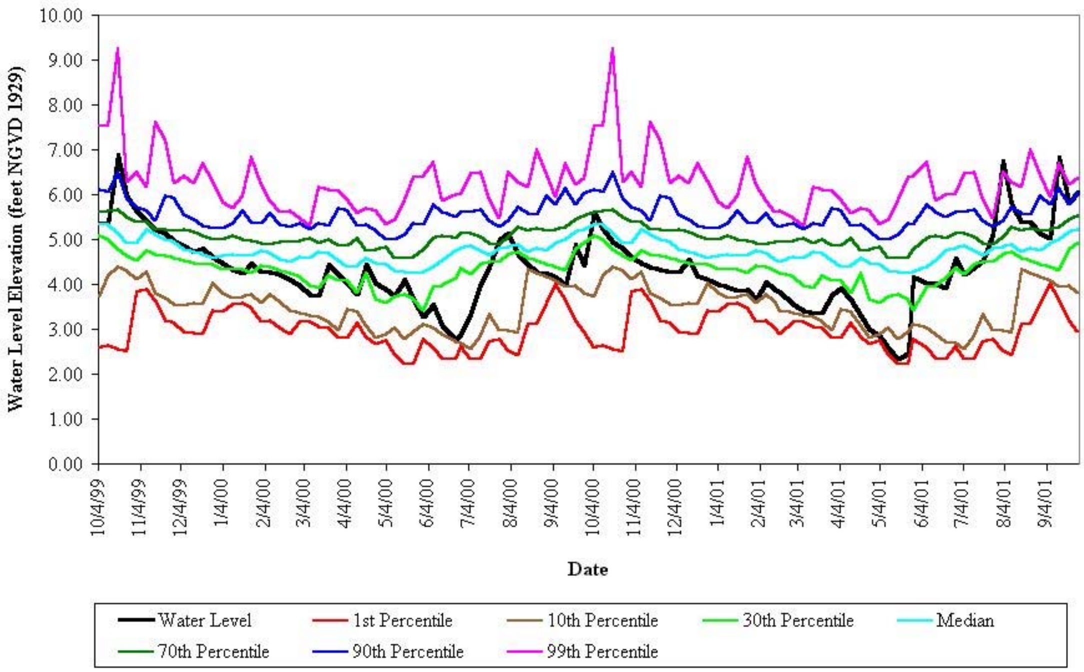

Figure 3-5. Hydrograph for M-1004 Surficial Aquifer monitoring well, October 1, 1999 to September 30, 2001

The first period of low groundwater levels began after Hurricane Irene passed over southern Florida October 14 through 16, 1999. The eastern part of the South Florida peninsula received between 10 and 20 inches of rain from Hurricane Irene. However, from mid-October 1999 to mid-April 2000, precipitation in the UEC was below normally recorded levels. As a result, the water level in the SAS dropped below its normal level from January 2000 to early April 2000 to within the lowest 10-to-30 percentile of recorded water level values (**figures 3-4** and **3-5**). A brief period of rainfall in April 2000 recharged the SAS, and the water level in the aquifer remained above its normal level until early May 2000. Again, from early May 2000 until early October 2000 the UEC received minimal rainfall and the water level in the aquifer dropped to within the lowest 1-to-10 percentile of recorded values for this period. Between October 3 and 4, 2000, a tropical depression (later named Tropical Storm Leslie) passed over the Florida peninsula, dumping 12-to-18 inches of rain along Florida's East Coast. This precipitation recharged the SAS, and water levels rose above normal levels.

The second decline in groundwater levels began in late November 2000, when the water level in the aquifer again dropped below normal. This low water level period lasted from late November 2000 to August 1, 2001. However, during this second period there were three-to-four periods of rainfall after early April 2001 that helped recharge the SAS. These periods of rainfall raised the water in the aquifer to above its normal level in the northern part of the UEC and to slightly below its normal level in the southern part of the region. Rainfall from Tropical Storm

Barry (August 1 through 4, 2001) and Tropical Storm Gabrielle (September 11 through 14, 2001) ended the drought, as water levels in the SAS rose above their normally recorded levels.

LOWER EAST COAST PLANNING AREA

Surficial Aquifer in Palm Beach County

The Surficial Aquifer in Palm Beach County is a shallow, unconfined aquifer consisting of unconsolidated quartz sand, limestone, sandstone, and shells (coquina). It is the principal source of potable water in the area (Shine et al., 1989). Between October 1, 1999 and September 30, 2001, water level trends in the aquifer were gauged from three real-time monitoring wells in the area (**Figure 3-1**).

From October 1, 1999 to September 30, 2001, water levels in the aquifer remained below the normal level during two periods. One period of low groundwater levels occurred from early December 1999 through the end of October 2000. The other period of low groundwater levels occurred between early November 2000 and early August 2001. Since the Surficial Aquifer is unconfined, it is principally recharged by rainfall. These periods of low groundwater levels occurred during periods of below-normal rainfall. **Figure 3-6** shows the water level elevation trend in monitoring well PB-565 in northern Palm Beach County during the drought. This well is depicted in this report because it best represents the water level trends in the aquifer during the drought that occurred between October 1, 1999 and September 30, 2001.

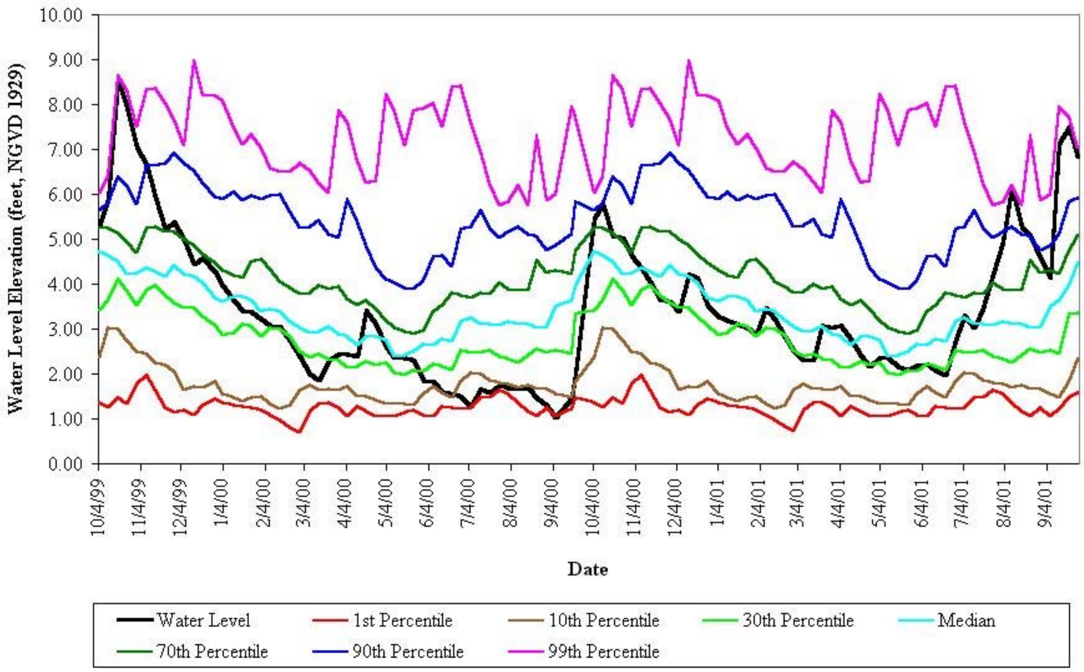

Figure 3-6. Hydrograph for PB-565 Surficial Aquifer monitoring well, October 1, 1999 to September 30, 2001

The first period of low groundwater levels began after Hurricane Irene passed over South Florida, October 14 through 16, 1999. From mid-October 1999 to mid-April 2000, precipitation in Palm Beach County was below normally recorded levels. As a result, the water level in the aquifer dropped to within the lowest 10-to-30 percentile of recorded values from January 2000 to early-April 2000 (**Figure 3-6**). A brief period of rainfall in April 2000 recharged the Surficial Aquifer, and the aquifer's water level remained above normal until early May 2000. Again, from early May 2000 until early October 2000, Palm Beach County received minimal rainfall and the water level in the aquifer dropped to within the lowest 1-to-10 percentile of recorded values for this period. Between October 3 and 4, 2000, a tropical depression (later named Tropical Storm Leslie) passed over the Florida peninsula, dropping substantial rainfall along the Southeast Coast. This precipitation recharged the Surficial Aquifer, and water levels rose above normal. The rainfall from this tropical depression effectively ended the 2000–2001drought's first phase.

The second phase of the decline began in late November 2000, when the aquifer's water level again dropped below normal. This second phase lasted from late November 2000 to August 1, 2001. However, during this second phase the decline in water levels was less precipitous, as there were three-to-four periods of rainfall between these dates that recharged the Surficial Aquifer. These periods of rainfall temporarily raised the aquifer's water level to above normal. Rainfall from Tropical Storm Barry (August 1 through 4, 2001) and Tropical Storm Gabrielle (September 11 through 14, 2001) ended the drought, as the water level in the Surficial Aquifer in Palm Beach County rose to within the highest one percentile of recorded levels.

Biscayne Aquifer, Miami-Dade, and Broward Counties

The Biscayne Aquifer is a shallow, unconfined aquifer consisting of highly permeable limestone and less-permeable sandy limestone and sand (Causaras, 1985 and 1987). The aquifer, which extends from southern Palm Beach County to Miami-Dade County, is generally more sandy to the north and east and contains more limestone and sandy limestone to the south and west. It is the principal source of potable water in the area (Shine et al., 1989). The aquifer is recharged when rainfall and water from numerous surface water bodies penetrate it. During dry periods, water stored in the Water Conservation Areas is released into District canals and used to maintain groundwater levels in the Biscayne Aquifer. The aquifer's high permeability allows rapid recharge from canal water (Randazzo and Jones, 1997) and from rainfall. Between October 1, 1999 and September 30, 2001, water level trends in the aquifer were gauged from 21 real-time monitoring wells in the area (**Figure 3-1**).

The water level in the Biscayne Aquifer exhibited different trends in different areas during the drought. In northern Broward County, the water level exhibited a similar trend as the SAS in Palm Beach County. There were two periods during which water levels dropped below normal. One period of low groundwater levels occurred from late December 1999 through the end of September 2000. The other occurred between early November 2000 and early August 2001. **Figure 3-6** is a hydrograph for monitoring well G-1260, located in northern Broward County.

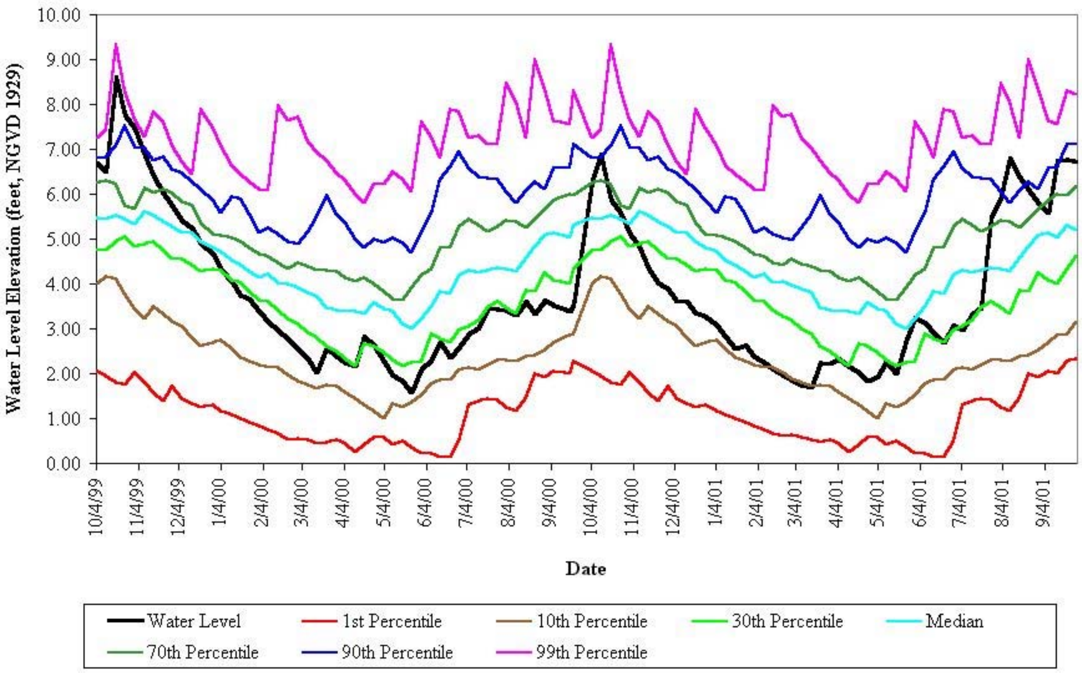

Figure 3-7. Hydrograph for the G-1260 Biscayne Aquifer monitoring well, October 1, 1999 to September 30, 2001

In northern Miami-Dade County, the water level in the Biscayne Aquifer had one extended period (mid-November 1999 to mid-March 2000) and several shorter periods when water levels were below normal. **Figure 3-8** is a hydrograph for monitoring well F-291, located in northern Miami-Dade County. There were also several peaks when the water level in the aquifer was significantly above normal. These high levels probably correspond to a recharge event due to rainfall or inflow from District canals.

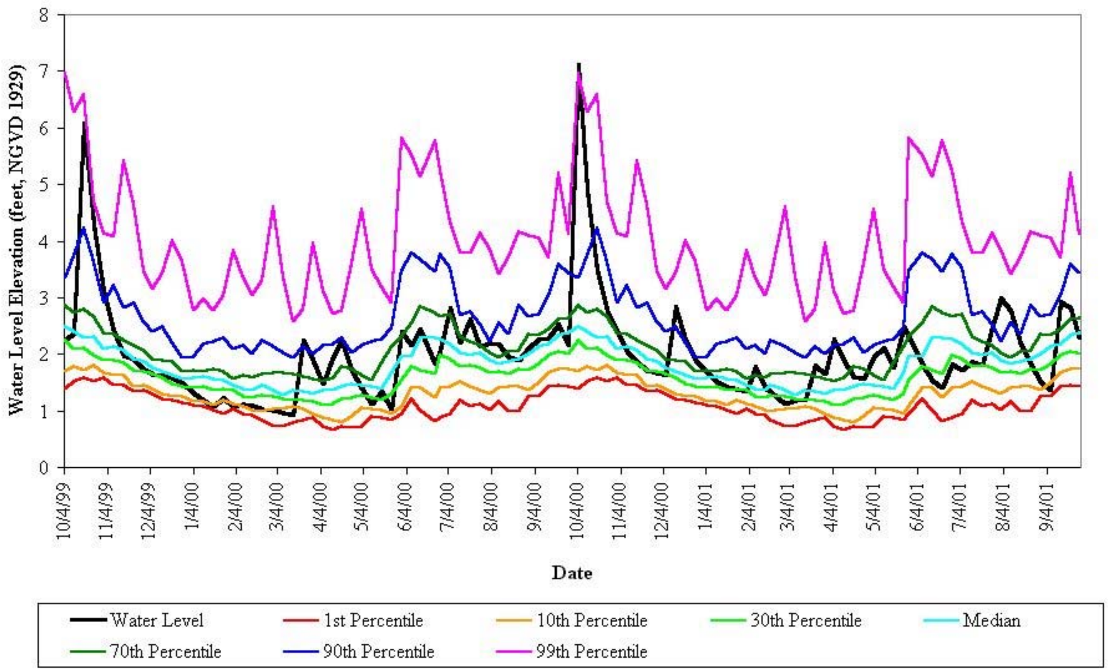

Figure 3-8. Hydrograph for F-291 Biscayne Aquifer monitoring well, October 1, 1999 to September 30, 2001

The water level in the Biscayne Aquifer, in southern Miami-Dade County near the coast, generally remained at or above the normal level through the 2000–2001 drought. **Figure 3-9** is a hydrograph for monitoring well G-1183, located in southern Miami-Dade County near a canal structure. However, inland around Homestead and Florida City, water levels were periodically at the lowest 1-to-10 percentile of historical levels, specifically during 2001. The low water levels in 2001 in south Miami-Dade County resulted from below-normal rainfall and lack of recharge from canals. When the water level in Lake Okeechobee dropped to critical levels, discharges into the District's canal system that supplies water to Miami-Dade County were reduced. The combination of below-normal rainfall and less recharge from surface water resulted in very little recharge to the Biscayne Aquifer and below-normal water levels. The hydrograph for monitoring well G-1183 (**Figure 3-9**) near a canal structure exemplifies that the water level in the aquifer remained fairly constant throughout the drought. This may indicate that the potential for saltwater intrusion was low during this time, as the head level in the canal behind the structure was near its normal level.

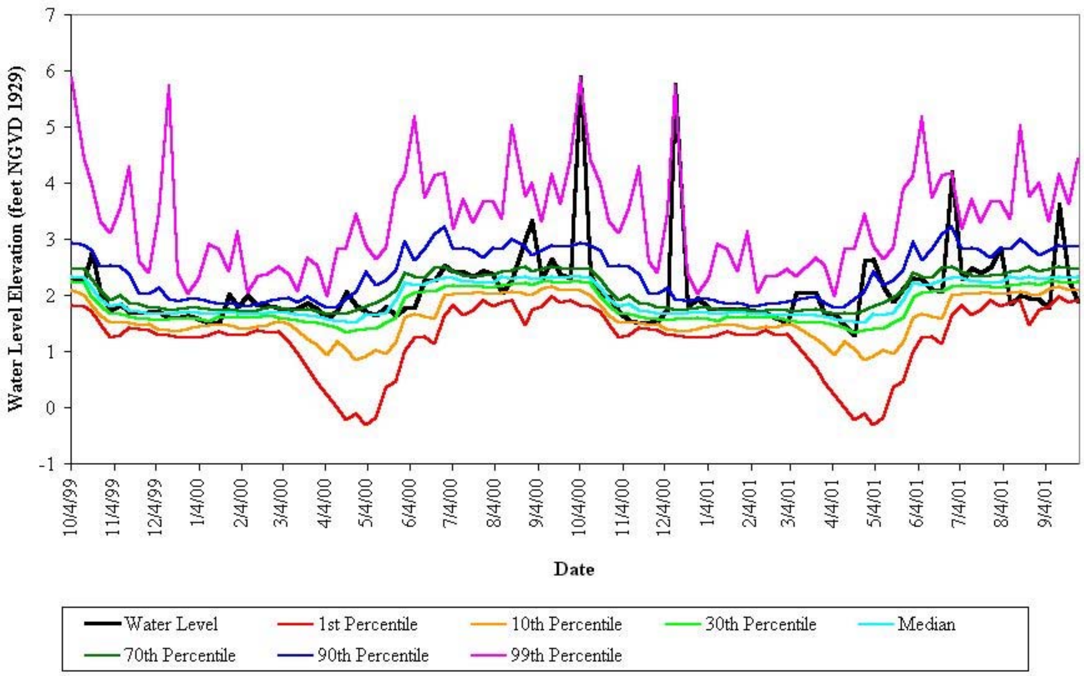

Figure 3-9. Hydrograph for G-1183 Biscayne Aquifer monitoring well, October 1, 1999 to September 30, 2001

LOWER WEST COAST PLANNING AREA

The four aquifers in the Lower West Coast (LWC) Planning Area are combined into two aquifer systems: the Surficial Aquifer System (SAS), consisting of the Surficial and Lower Tamiami aquifers; and the Intermediate Aquifer System (IAS), consisting of the Sandstone and Mid-Hawthorn aquifers. The IAS is the main source of potable water in the LWC (Randazzo and Jones, 1997). The sections below describe the water level trends in these aquifers between October 1, 1999 and September 30, 2001.

Surficial Aquifer

The Surficial Aquifer is the upper-most aquifer of the SAS. It is a shallow, unconfined aquifer consisting of undifferentiated deposits. The primary use of groundwater from this aquifer is agricultural irrigation.

During the drought, there were two distinct periods of low water levels in the Surficial Aquifer. One period occurred from early January 2000 through early August 2000. The other occurred between mid-October 2000 and early-August 2001. Since the Surficial Aquifer is unconfined, it is principally recharged by rainfall. These periods of low groundwater levels occurred during periods of below-normal rainfall. **Figure 3-10** shows the water level elevation trend in monitoring well C-492 (Collier County) during the drought. This well is shown in this report because it best represents the water level trends in the aquifer between October 1, 1999 and September 30, 2001.

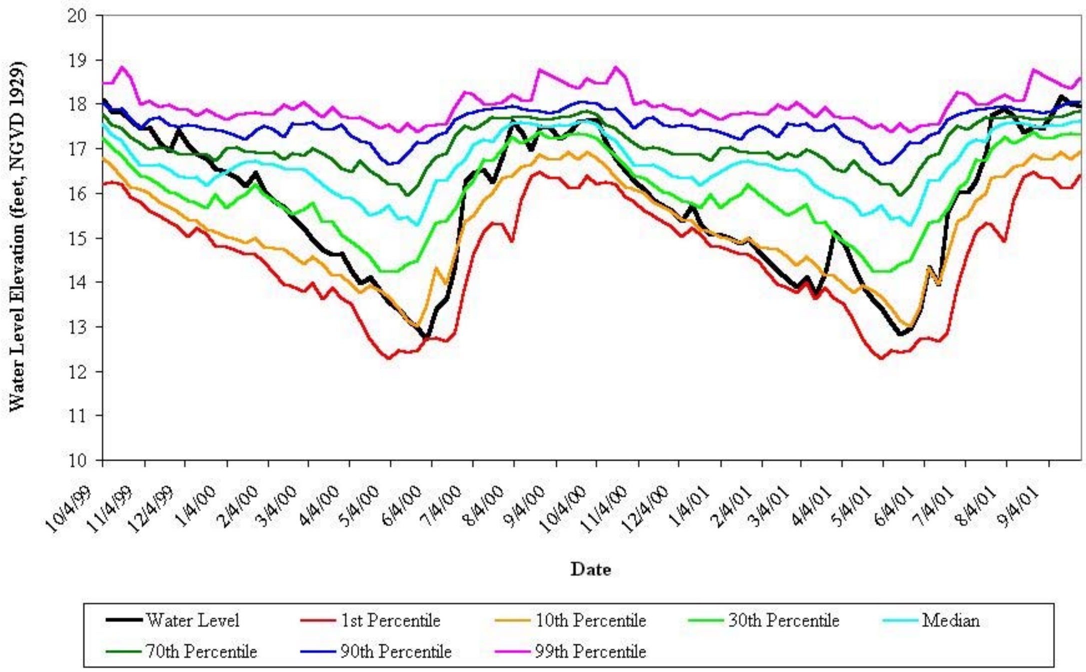

Figure 3-10. Hydrograph for C-492 Surficial Aquifer monitoring well, October 1, 1999 to September 30, 2001

The first period of low groundwater levels began after Hurricane Irene passed over South Florida, October 14 through 16, 1999. However, from mid-October 1999 to mid-April 2000, precipitation in the LWC was below normally recorded levels. As a result, the water level in the Surficial Aquifer dropped below normal to within the lowest 10th percentile of recorded water levels. From mid-July 2000 until early October 2000, the LWC received rainfall and the water level in the aquifer rose to near its normal level. Rainfall between October 3 and 4, 2000 from a tropical depression (later named Tropical Storm Leslie) recharged the Surficial Aquifer, and its water level rose to normal.

The second period of the decline began in mid-October 2000, when the water level in the aquifer again dropped below normal. This period lasted until August 1, 2001, when precipitation from Tropical Storm Barry recharged the aquifer and brought the water level above normal. Rainfall from Tropical Storm Barry (August 1 through 4, 2001), and later from Tropical Storm Gabrielle (September 11 through 14, 2001), ended the drought, as the water level in the Surficial Aquifer rose above its normally recorded level.

Lower Tamiami Aquifer

The Lower Tamiami Aquifer is the lower-most aquifer of the SAS. It is semi-confined to confined and consists of sandy, shelly limestone, and calcareous sandstone (Wedderburn et al., 1982). This aquifer supplies water to municipalities, domestic self-suppliers, and is also used for agricultural irrigation.

Between October 1, 1999 and September 30, 2001 there were two distinct periods of declining water levels in the Lower Tamiami Aquifer. However, the only extended period of time when the water level in the aquifer was below normal was between mid-November 1999 and mid-April 2000. There were other, shorter periods during the drought when water levels were below the normal level for the aquifer. However, these periods lasted no more than two months. Since the Lower Tamiami Aquifer is semi-confined, it is principally recharged from the overlying Surficial Aquifer. Low groundwater levels in the aquifer occurred during periods of below-normal rainfall. The below-normal rainfall meant that the overlying Surficial Aquifer was not being recharged and therefore could not recharge the Lower Tamiami Aquifer. **Figure 3-11** depicts the water level elevation trend in monitoring well L-738 (Lee County). This well is depicted because it best represents the water level trends in the aquifer during the drought that occurred between October 1, 1999 and September 30, 2001.

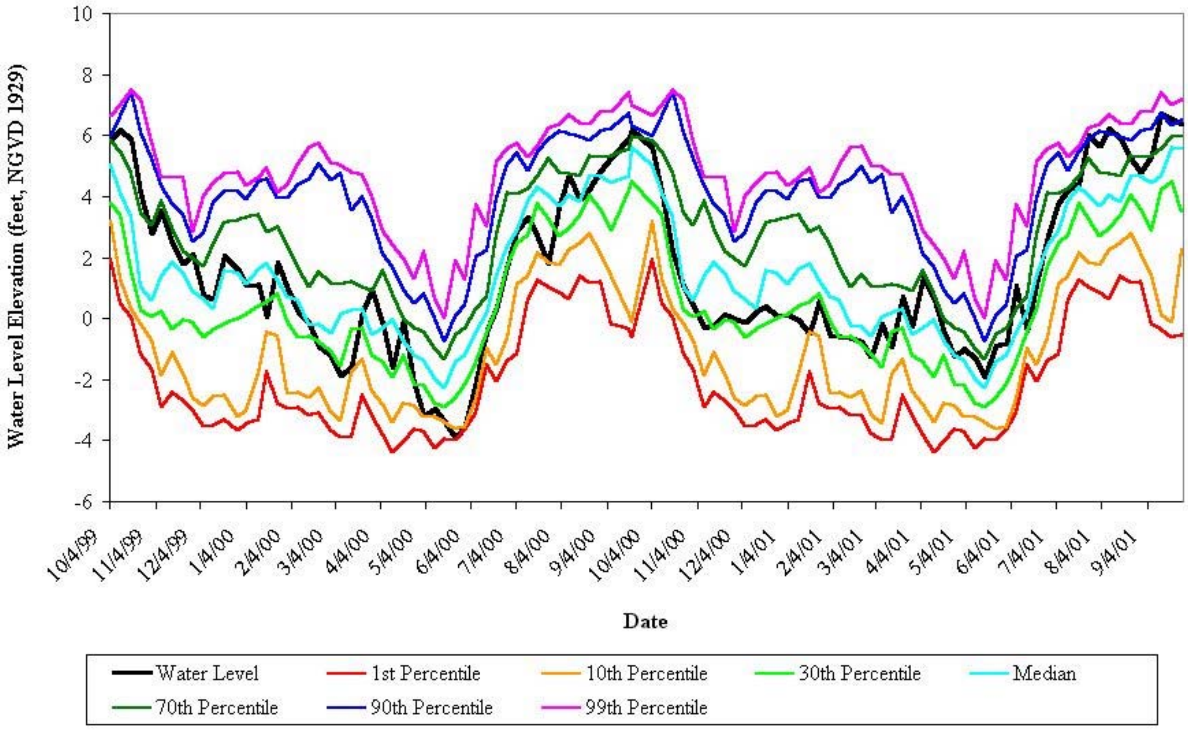

Figure 3-11. Hydrograph for L-738 Lower Tamiami Aquifer monitoring well, October 1, 1999 to September 30, 2001

After Hurricane Irene passed over South Florida, the water level in the Lower Tamiami Aquifer began to decline. The water level in the aquifer periodically dropped below normal for a brief period of time in both February and March 2000. Several peaks on the hydrograph for monitoring well L-738 (**Figure 3-11**) during this time indicate recharge to the aquifer. These recharge events raised the water level in the Lower Tamiami above normal levels. From early May to early July 2000, the water level in the Lower Tamiami Aquifer dropped to within the lowest 1-to-10 percentile of recorded water levels for the aquifer. The aquifer's water level began to rise in early July and was at its normal level by early August 2000. There was another brief period in mid-to-late August 2000, when the water level in the aquifer dipped below normal. Wet-season rainfall and precipitation from a tropical depression (later named Tropical Storm Leslie) in early October recharged the Lower Tamiami Aquifer, and the water level rose above normal.

In late October 2000, the water level in the Lower Tamiami Aquifer underwent a precipitous drop to within the lowest 10-to-30 percentile of recorded water levels by mid-November 2000. This period of below-normal water levels lasted until mid-April 2001, when, after several rainfall events, the water level in the aquifer returned to normal. It remained at normal levels until rainfall from Tropical Storm Barry (August 1 through 4, 2001) and Tropical Storm Gabrielle (September 11 through 14, 2001) ended the drought and raised the water level in the Lower Tamiami Aquifer significantly above normal.

Sandstone Aquifer

The Sandstone Aquifer is the upper-most aquifer of the IAS. It is a confined aquifer and is separated from the overlying SAS by a confining layer of green/gray clay. The Sandstone Aquifer is composed of sandy limestones, sandstones, sandy dolomites, and calcareous sands (Wedderburn et al., 1982). The aquifer's productivity is highly variable. Nonetheless, it manages to supply groundwater to utilities and for irrigation (Wedderburn et al., 1982).

From October 1, 1999 to September 30, 2001, there were two distinct periods of low water levels in the Sandstone Aquifer. One period occurred from early January through mid-August 2000. The other occurred between early November 2000 and mid-June 2001. Since the Sandstone Aquifer is confined, it is recharged by the overlying aquifers. The low groundwater levels in the aquifer occurred during periods of below-normal rainfall, when the overlying aquifers were not being recharged and, therefore, could not recharge the Sandstone. **Figure 3-12** is a hydrograph for monitoring well HE-556 in Hendry County. This well is presented in this report because it best represents the drought's effect on the Sandstone Aquifer's water level.

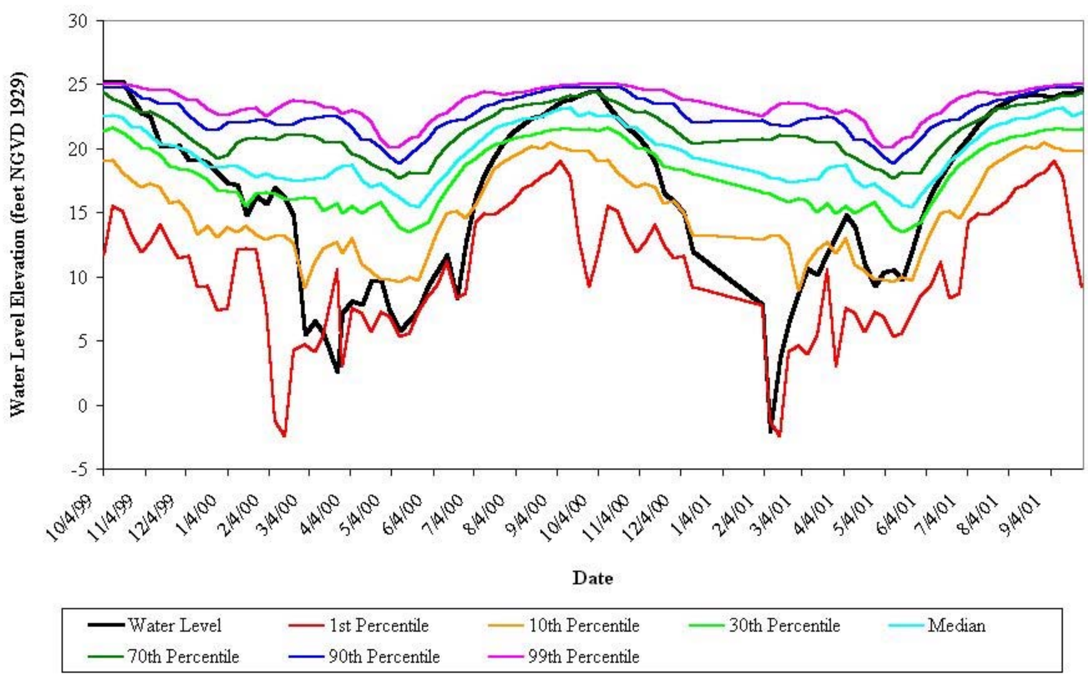

Figure 3-12. Hydrograph for HE-556 Sandstone Aquifer monitoring well, October 1, 1999 to September 30, 2001

After receiving significant recharge from Hurricane Irene, the water level in the Sandstone Aquifer began to drop as the District entered a period of below-normal rainfall in late October 1999. By early January 2000 the water level in the Sandstone Aquifer had dropped below normal, and it underwent a precipitous drop in late February/early March 2000 to within 1-to-10 percentile of its lowest level. It remained there until early July, when it began to rise. By early August the aquifer's water level was back above normal. Rainfall from a tropical depression (later named Tropical Storm Leslie) in early October 2000 helped to significantly raise the aquifer's water level to above normal.

By mid October 2000 the water level in the Sandstone Aquifer again fell below normal as it underwent another precipitous drop. By early February 2001, the water level in the aquifer was at its lowest 1 percentile of recorded levels. When water restrictions went into effect, the water level in the aquifer rose to within its lowest 10-to-30 percentile of recorded values by mid-March 2001, showing the positive effects of the water restrictions. By mid-May 2001 the water level in the Sandstone Aquifer again rose due to recharge of the overlying aquifers from wet-season rainfall. In mid-June 2001 the water level in the aquifer was back above normal. Rainfall from tropical storms Barry and Gabrielle further recharged the overlying aquifers and raised the water level in the Sandstone Aquifer significantly above normal, effectively ending the drought.

Mid-Hawthorn Aquifer

The Mid-Hawthorn Aquifer is confined and is the lowermost aquifer of the IAS. It is separated from the overlying Sandstone Aquifer by a confining layer of clay. The Mid-Hawthorn Aquifer consists of limestone, dolomite, and sandstone and derives its permeability from intergranular and moldic porosity and fractures/solution openings (Wedderburn et al., 1982). The aquifer is not always productive and is also relatively thin (it rarely exceeds 80 feet in thickness), compared to other aquifers within the District (SFWMD, 2000). The aquifer extends to the south and east, where it terminates near the Lee-Hendry counties' line. The water quality in the aquifer is poor, as it yields mostly saline water in much of the LWC (SFWMD, 2000). Groundwater from the aquifer is used by private wells in areas where city water is not provided. It is also occasionally used for agricultural irrigation.

From October 1, 1999 to September 30, 2001, there were two distinct periods of low water levels in the Mid-Hawthorn Aquifer. The first period occurred from mid-February through mid-June 2000. The second occurred between early November 2000 and mid-July 2001. The periods of low groundwater levels in the aquifer occurred during periods of below-normal rainfall, meaning that the overlying aquifers were not being recharged and, therefore, could not recharge the Mid-Hawthorn Aquifer. **Figure 3-13** is a hydrograph for monitoring well L-2644 in Lee County. This well is presented in this report because it best represents the 2000-2001 drought's effects on the water level in the Mid-Hawthorn Aquifer.

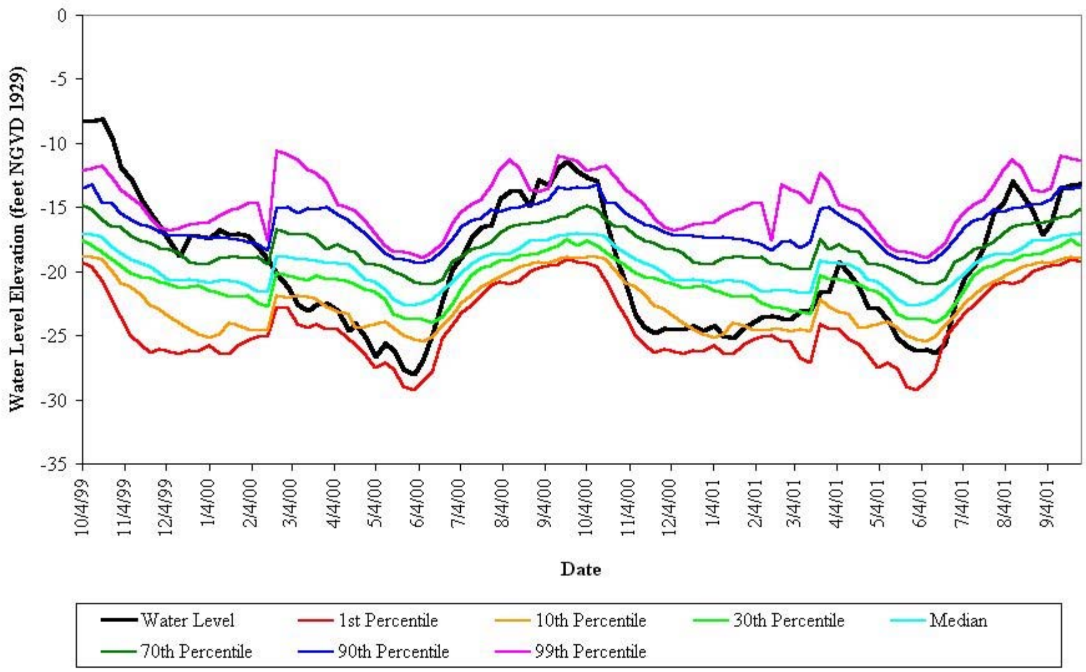

Figure 3-13. Hydrograph for L-2644 Mid-Hawthorn Aquifer monitoring well, October 1, 1999 to September 30, 2001

After receiving significant recharge from Hurricane Irene, the water level in the Mid-Hawthorn Aquifer started to drop in late October 1999, as the District entered a period of below-normal rainfall. By mid-February 2000 the aquifer's water level dropped to below normal and then steadily declined. By mid-March 2000 the water level had dropped to within 1-to-10 percentile of its lowest level, where it remained until early June 2000, when it began to rise. By late June, the water level in the aquifer was back above normal. Rainfall from a tropical depression (later named Tropical Storm Leslie) in early October 2000 significantly helped to raise the water level in the aquifer to above normal.

By late October 2000 the water level in the Mid-Hawthorn Aquifer was back below normal, as it underwent a precipitous drop. By early November 2000 it was at the lowest 1-to-10 percentile of its recorded levels. It remained there until early February 2001, when water restrictions went into effect. After the District imposed water restrictions, the water level in the aquifer rose and briefly returned to normal in early April 2001. However, by mid-June 2001 the water level in the Mid-Hawthorn Aquifer had declined to within the lowest 1 percentile of its recorded values. By early July 2001 the water level in the aquifer was back above normal, as wet-season rainfall recharged the overlying aquifers. Rainfall from tropical storms Barry and Gabrielle further recharged the overlying aquifers and raised the water level in the Mid-Hawthorn Aquifer significantly above its normal level, effectively ending the drought.

MONTHLY VOLUME OF PUMPED GROUNDWATER

From December 1999 to September 2001, nine counties reported the quantities of water withdrawn for water supply purposes from the aquifers described in the last section of this report. The average daily amount of water withdrawn per month in each county during this period is presented in **Table 3-2**.

Table 3-2. Average daily groundwater withdrawals, by county

County	Average Daily MGD Dec '99	Average Daily MGD Jan '00	Average Daily MGD Feb '00	Average Daily MGD Mar '00	Average Daily MGD Apr '00
Broward	135.63	142.38	151.94	150.10	144.34
Collier	53.23	55.80	59.12	58.33	55.82
Hendry	4.63	4.16	4.26	4.31	4.15
Lee	64.75	62.32	70.13	70.67	76.09
Miami-Dade	363.45	374.14	383.39	380.42	378.93
Monroe	16.02	17.19	18.07	18.78	18.09
Okeechobee	1.86	2.21	2.46	2.40	2.21
Orange	141.80	142.34	156.10	170.32	178.71
Palm Beach	199.08	203.53	216.66	223.52	218.12
Total	**980.45**	**1,004.06**	**1,062.13**	**1,078.86**	**1,076.46**

County	Average Daily MGD May '00	Average Daily MGD June '00	Average Daily MGD July '00	Average Daily MGD Aug '00	Average Daily MGD Sep '00
Broward	154.40	143.58	135.82	139.28	132.54
Collier	55.78	45.84	45.39	39.39	37.89
Hendry	3.44	3.67	3.44	3.79	3.67
Lee	77.16	52.19	44.07	46.27	46.37
Miami-Dade	396.52	376.32	371.04	375.38	373.65
Monroe	18.90	16.56	17.98	16.66	15.15
Okeechobee	2.47	2.07	1.97	1.97	2.02
Orange	207.59	199.12	168.21	163.27	155.93
Palm Beach	244.78	225.66	208.35	210.55	203.23
Total	**1,161.04**	**1,065.00**	**996.28**	**996.55**	**970.46**

County	Average Daily MGD Nov ’00*	Average Daily MGD Jan ’01	Average Daily MGD Feb ’01	Average Daily MGD Mar ’01	Average Daily MGD Apr ’01
Broward	149.54	130.58	132.62	124.40	123.97
Collier	55.99	51.51	51.09	49.34	48.69
Hendry	3.59	3.34	3.61	3.54	3.41
Lee	74.96	65.14	66.97	61.21	59.99
Miami-Dade	387.11	343.14	351.59	341.85	350.68
Monroe	16.69	16.28	16.89	16.95	15.85
Okeechobee	2.38	2.30	2.29	2.22	2.08
Orange	170.33	139.57	137.70	137.94	154.97
Palm Beach	222.57	201.12	198.92	193.44	193.52
Total	**1,083.18**	**952.99**	**961.68**	**930.90**	**953.18**

*No data available for October 2000

County	Average Daily MGD May ’01	Average Daily MGD June ’01	Average Daily MGD Jul ’01	Average Daily MGD Aug ’01	Average Daily MGD Sep ’01
Broward	119.93	116.23	115.01	125.93	114.13
Collier	49.38	45.18	38.41	41.96	39.78
Hendry	3.04	2.83	2.78	3.24	3.13
Lee	65.94	53.96	41.24	45.78	39.71
Miami Dade	346.04	353.45	348.00	355.02	340.10
Monroe	14.94	15.68	15.25	15.17	13.54
Okeechobee	2.00	1.83	2.03	1.86	1.86
Orange	158.40	143.08	140.68	139.91	132.25
Palm Beach	186.34	170.63	167.84	186.11	110.64
Total	**946.02**	**902.87**	**871.24**	**914.99**	**795.14**

The data in **Table 3-2** indicate that water restrictions imposed in 2001 were more effective in controlling groundwater withdrawals than those imposed in 2000. Generally, in 2000, the quantity of groundwater withdrawn during the drought was cyclical, i.e., it would decrease one month and increase the next. Throughout 2001, average daily groundwater withdrawals in each county decreased each month. The effects of the decrease are noticeable in the semi-confined to confined aquifers in the LWC. The hydrographs presented in the previous section for the Sandstone and Mid-Hawthorn aquifers show a slight increase in the water level in each aquifer after water restrictions went into effect and groundwater withdrawals were reduced.

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Chapter 4: Conclusions and Recommendations

Wossenu Abtew, R. Scott Huebner, and Simon Sunderland

CONCLUSIONS AND RECOMMENDATIONS

Droughts and water shortages have the potential to increase in severity and frequency as the demand for water increases in South Florida. A minimum of one severe drought every decade can be expected. Water management decision making should incorporate drought monitoring and recurrence probability. Rainfall deficit, Palmer Drought Severity Index, climatological forecasts, surface water and groundwater levels, and water demand parameters are essential to monitor. A system-wide approach is necessary to effectively deal with wildfire mitigation, drought, and water management.

Further, it is important to not only develop a drought monitoring system that will alert the public and others to the imminence of drought, but also to incorporate drought management as part of water supply planning and operational decision making. At the onset of a drought, the impact can be reduced by implementation of drought mitigation measures, specifically, increasing water supply, reducing water demand, and minimizing the drought's impact (Rossi, 2000). Suggestions for increasing the water supply include relaxing minimum lake levels, developing new, or less-used, sources, and reusing water. Recommendations for reducing water demand include implementation of water use restrictions and education regarding water conservation methods and application. Suggestions for minimizing the impact of a drought include temporary re-allocation of water resources and the use of subsidies.

REFERENCES

Rossi, G. 2000. *Drought Mitigation Measures: A Comprehensive Framework*. Drought and Drought Mitigation in Europe. J.V. Vogt and F. Somma (eds.), pp. 233–246. Kluwer Academic Publishers, Boston.

APPENDIX 2A-1

Wossenu Abtew and R. Scott Huebner

SUMMARY

This appendix contains illustrations of historical annual rainfall, lake flows and water levels, and Water Conservation Areas' water levels.

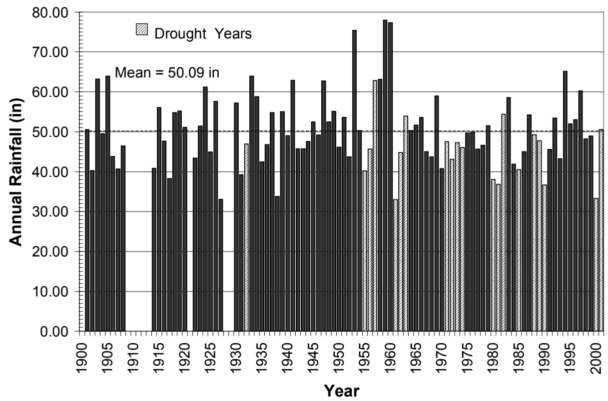

Figure 2A-1-1. Historical annual rainfall for Upper Kissimmee Rain Area and regional drought years

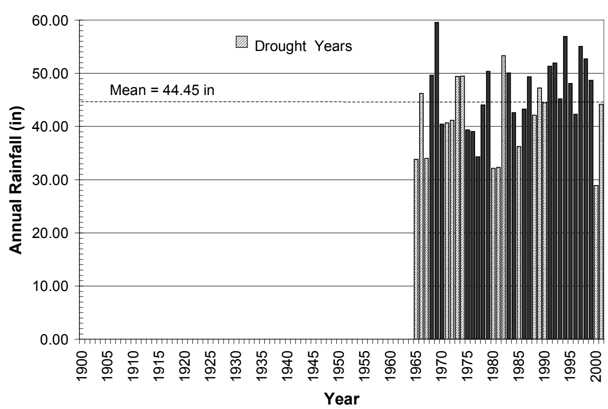

Figure 2A-1-2. Historical annual rainfall for Lower Kissimmee Rain Area and regional drought years

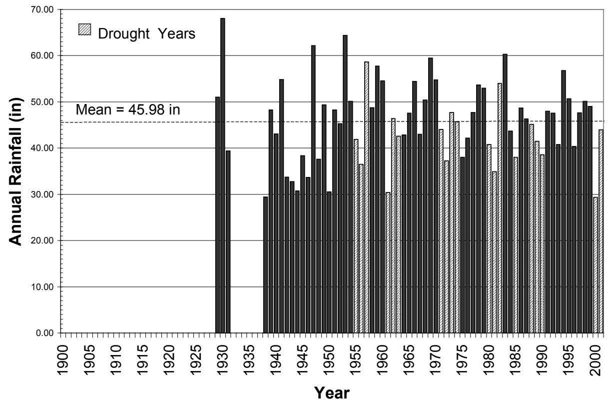

Figure 2A-1-3. Historical annual rainfall for Lake Okeechobee Rain Area and regional drought years

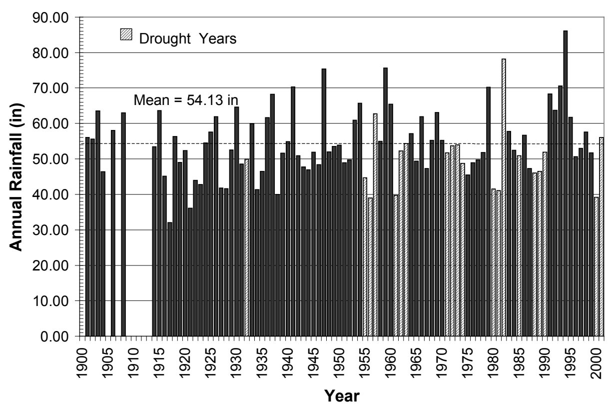

Figure 2A-1-4. Historical annual rainfall for Martin/St. Lucie Rain Area and regional drought years

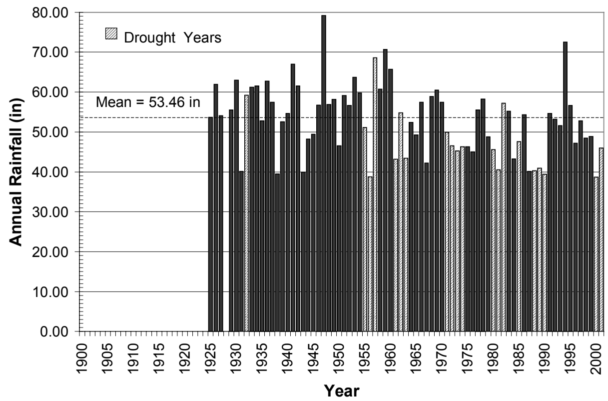

Figure 2A-1-5. Historical annual rainfall for East EAA Rain Area and regional drought years

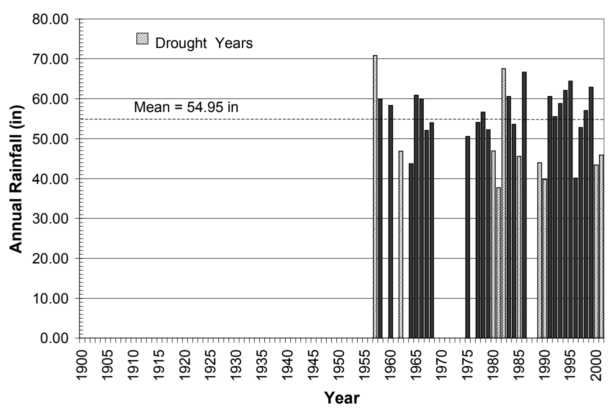

Figure 2A-1-6. Historical annual rainfall for West Ag. Rain Area and regional drought years

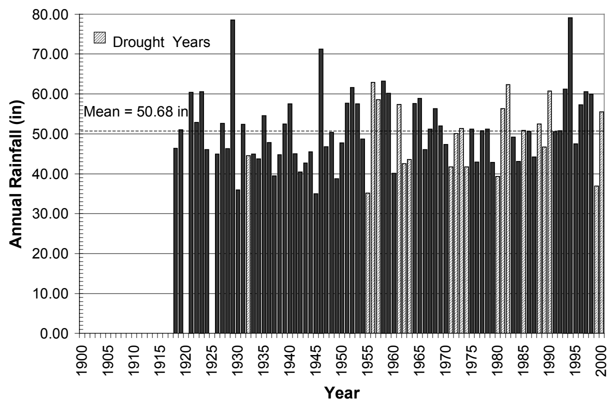

Figure 2A-1-7. Historical annual rainfall for East Caloosahatchee Rain Area and regional drought years

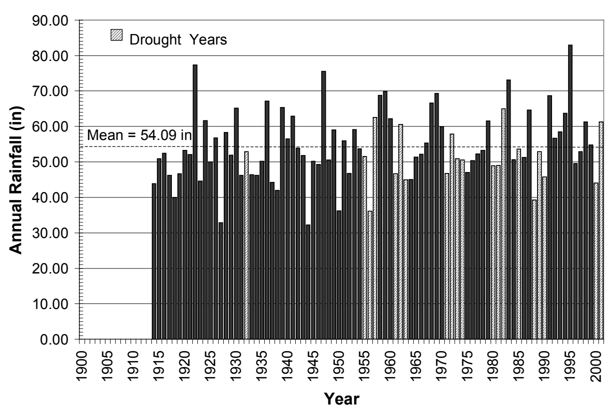

Figure 2A-1-8. Historical annual rainfall for Southwest Coast Rain Area and regional drought years

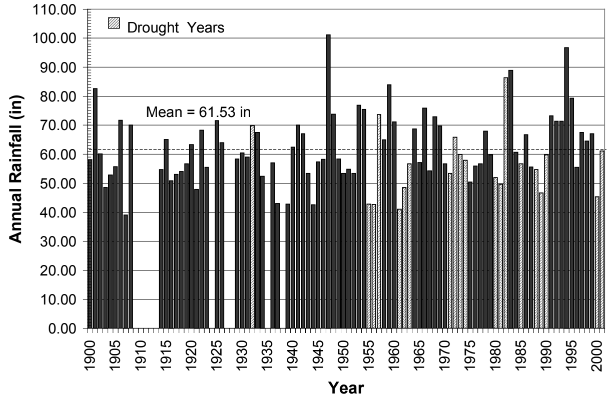

Figure 2A-1-9. Historical annual rainfall for Palm Beach Rain Area and regional drought years

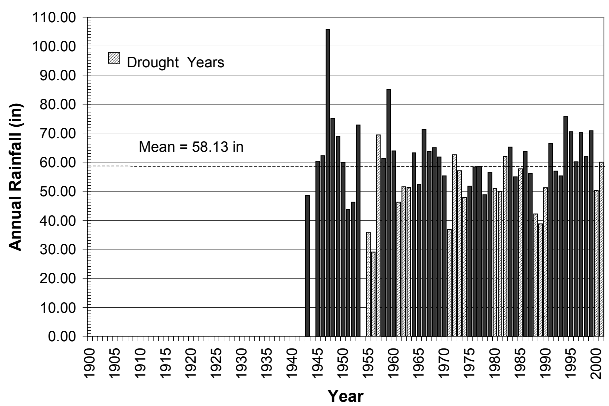

Figure 2A-1-10. Historical annual rainfall for Broward Rain Area and regional drought years

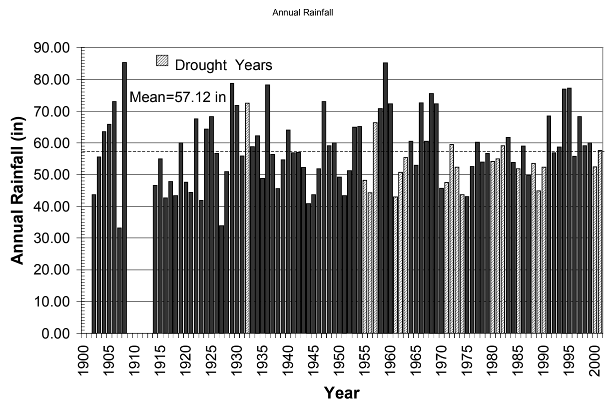

Figure 2A-1-11. Historical annual rainfall for Miami-Dade Rain Area and regional drought years

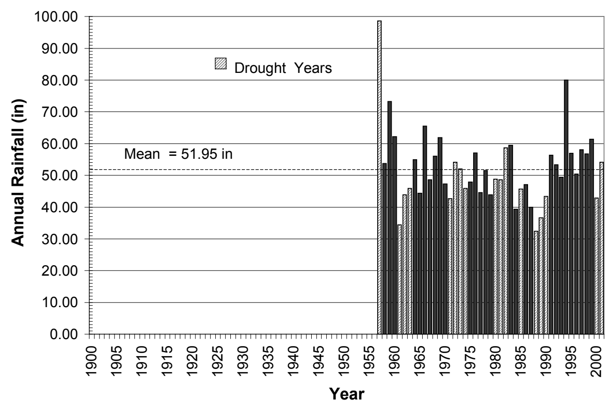

Figure 2A-1-12. Historical annual rainfall for WCA-1 and 2 Rain Area and regional drought years

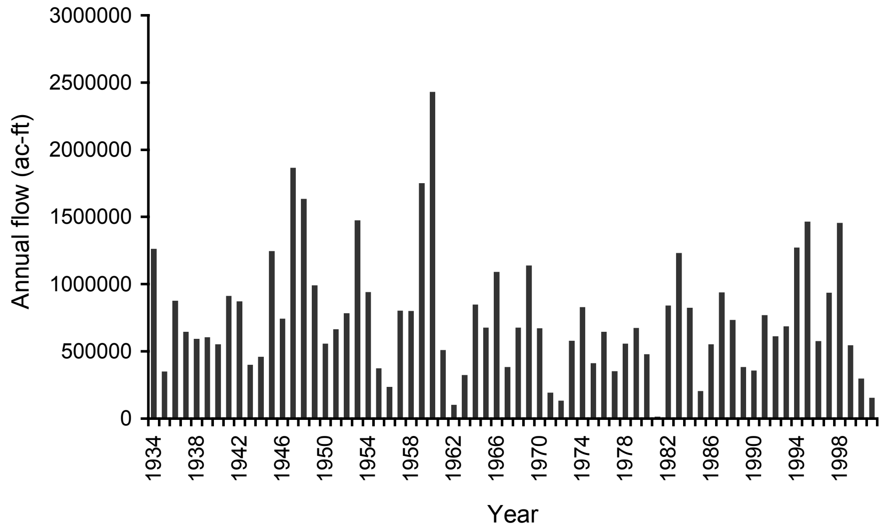

Figure 2A-1-13. Historical outflows from Lake Kissimmee through S-65 structure

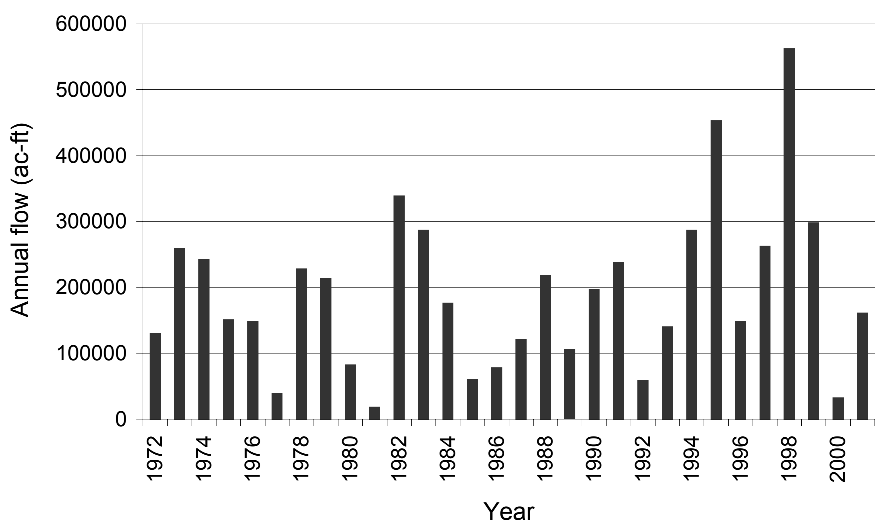

Figure 2A-1-14. Historical outflows from Lake Istokpoga through S-68 structure

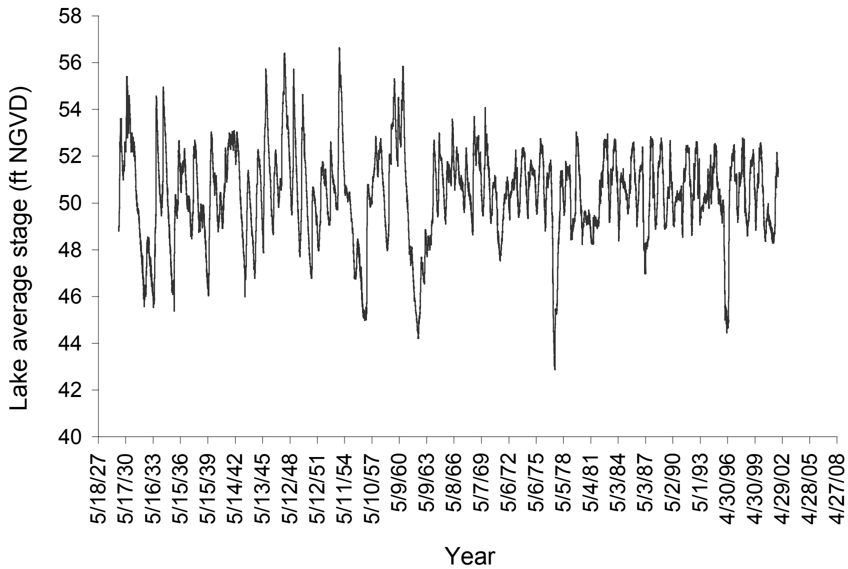

Figure 2A-1-15. Historical daily water level for Lake Kissimmee

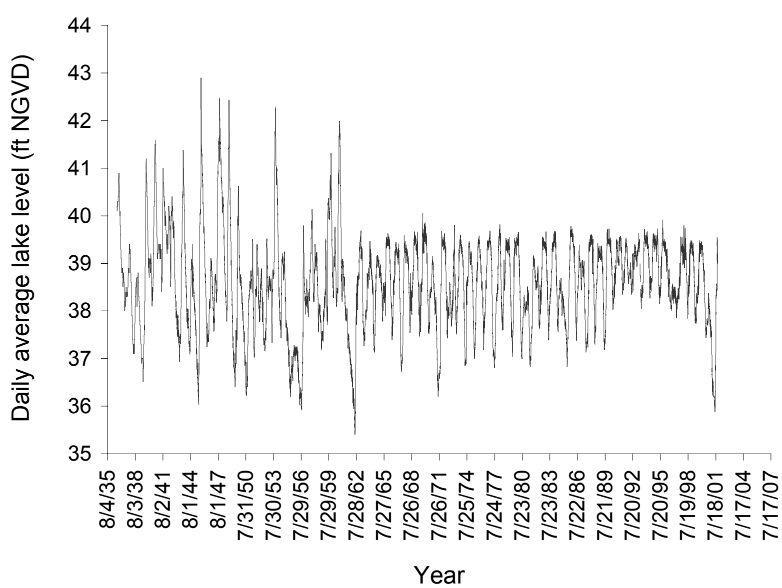

Figure 2A-1-16. Historical daily water level for Lake Istokpoga

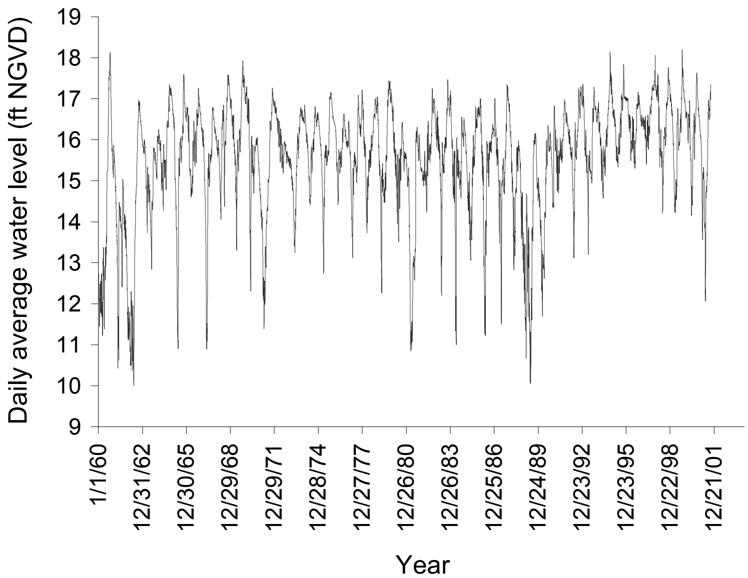

Figure 2A-1-17. Historical daily water level for Water Conservation Area 1-A

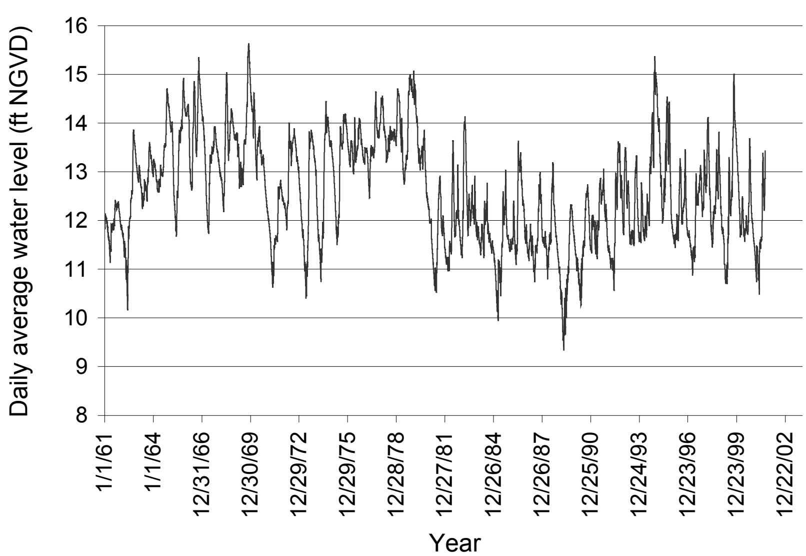

Figure 2A-1-18. Historical daily water level for Water Conservation Area 2-A

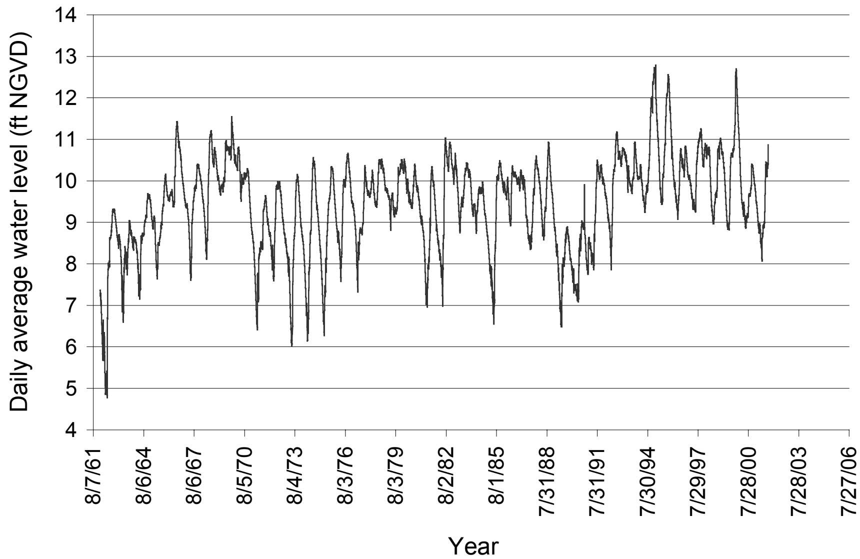

Figure 2A-1-19. Historical daily water level for Water Conservation Area 3-A

APPENDIX 2A-2

Wossenu Abtew and R. Scott Huebner

SUMMARY

This appendix contains illustrations of Stormwater Treatment Areas, Water Conservation Areas, Everglades National Park, and coastal flows during the drought period.

Table 2A-2-1. STA-1W inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	G302_S	STA-1W Inflow	G251_P	G310_P	STA-1W Outflow
1999	October	16,359	16,359	18,829	0	18,829
1999	November	9,682	9,682	10,701	0	10,701
1999	December	13,020	13,020	12,480	0	12,480
2000	January	17,787	17,787	12,763	0	12,763
2000	February	3,418	3,418	8,316	0	8,316
2000	March	14,260	14,260	9,693	0	9,693
2000	April	11,238	11,238	10,986	0	10,986
2000	May	8,412	8,412	11,400	0	11,400
2000	June	4,823	4,823	1,557	0	1,557
2000	July	15,587	15,587	14,396	3,667	18,063
2000	August	16,613	16,613	10,592	5,378	15,970
2000	September	17,497	17,497	8,191	7,339	15,531
2000	October	12,337	12,337	8,692	13,804	22,496
2000	November	0	0	1	1,178	1,179
2000	December	508	508	0	500	500
2001	January	0	0	0	106	106
2001	February	0	0	0	0	0
2001	March	4,702	4,702	534	1,038	1,572
2001	April	719	719	1,065	1,078	2,143
2001	May	917	917	0	0	0
2001	June	5,171	5,171	0	232	232
2001	July	40,219	40,219	0	40,721	40,721
2001	August	33,957	33,957	0	49,004	49,004
2001	September	47,936	47,936	1,085	56,018	57,103
Total		**295,162**	**295,162**	**141,281**	**180,063**	**321,344**

Table 2A-2-2. STA-5 inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	G342A	G342B	G342C	G342D	G349B_P	G350B_P	STA5_TMP	STA 5 Inflow	G344A	G344B	G344C	G344D	STA 5 Outflow
1999	October	2,894	1,876	1,319	1,334	0	0	0	7,422	4,159	4,645	4,382	4,082	17,267
1999	November	5	10	8	4	0	0	0	27	4	6	4	1	15
1999	December	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	January	-3	-1	-1	-2	0	0	0	-7	0	0	15	0	15
2000	February	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	March	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	April	3	10	168	441	0	0	0	622	0	0	0	0	0
2000	May	0	0	0	-1	855	839	0	1,692	0	0	0	0	0
2000	June	0	0	0	129	485	919	0	1,533	0	0	0	0	0
2000	July	2	3	2,716	3,149	0	0	0	5,871	3	0	3,391	2,390	5,784
2000	August	908	2,060	4,432	4,052	70	69	0	11,591	1,595	1,647	3,023	2,948	9,213
2000	September	2,621	5,468	5,563	3,190	2	1	0	16,845	4,744	5,145	2,529	2,988	15,406
2000	October	2,549	6,095	3,836	4,898	2	2	0	17,383	6,749	8,991	5,923	4,840	26,503
2000	November	3	3	225	271	0	0	0	502	0	7	60	58	125
2000	December	3	5	3	2	0	0	0	13	13	10	6	6	35
2001	January	2	0	0	0	0	0	0	2	11	7	6	0	24
2001	February	4	4	0	1	442	0	449	900	4	1	1	-3	4
2001	March	154	272	873	851	338	477	1,323	4,288	0	0	0	0	0
2001	April	0	1	220	240	0	0	0	460	0	0	0	0	0
2001	May	0	0	0	0	0	0	1,255	1,255	0	0	0	0	0
2001	June	2,822	3,422	3,646	2,955	0	0	134	12,980	0	0	0	0	0
2001	July	4,932	6,095	5,788	4,983	0	4	0	21,802	6,617	5,863	4,017	624	17,121
2001	August	6,464	8,142	7,073	6,104	0	8	0	27,790	10,629	7,650	8,999	-1,996	25,282
2001	September	8,188	9,993	8,414	7,133	0	0	0	33,727	13,831	11,494	10,999	5,574	41,897
Total		**31,550**	**43,458**	**44,284**	**39,733**	**2,194**	**2,320**	**3,161**	**166,701**	**48,360**	**45,465**	**43,354**	**21,514**	**158,693**

Table 2A-2-3. STA-6 inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	G600_P	STA-6 Inflow	STA6_OUT	G354_C	G393_C	STA-6 Outflow
1999	October	14,734	14,734	18,847			18,847
1999	November	5,822	5,822	5,232			5,232
1999	December	1,931	1,931	1,136			1,136
2000	January	1,044	1,044	0			0
2000	February	965	965	0			0
2000	March	283	283	0			0
2000	April	1,573	1,573	41			41
2000	May	0	0	0			0
2000	June	1,461	1,461	0			0
2000	July	5,338	5,338	3,724			3,724
2000	August	3,568	3,568	3,054			3,054
2000	September	6,667	6,667	5,415			5,415
2000	October	12,690	12,690	11,693			11,693
2000	November	2,300	2,300	343			343
2000	December	894	894	0			0
2001	January	0	0	0			0
2001	February	886	886	0			0
2001	March	4,928	4,928		1,138	870	2,008
2001	April	662	662		253	227	480
2001	May	294	294		0	0	0
2001	June	6,211	6,211		1,622	1,152	2,775
2001	July	4,762	4,762		1,488	1,100	2,588
2001	August	3,169	3,169		996	692	1,689
2001	September	8,895	8,895		3,617	2,234	5,852
Total		**89,079**	**89,079**	**49,486**	**9,115**	**6,276**	**64,877**

Table 2A-2-4. LNWR inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	G300	G301	S6	G251	G310	ACME	LNWR Inflow	S10A	S10C	S10D	S10E	S39	G94ABC	LNWR Outflow
1999	October	0	42,883	74,356	18,829	0	10,096	146,165	0	83,599	84,432	73,559	0	17,421	259,012
1999	November	9,546	-6,233	16,487	10,701	0	2,708	39,441	0	0	19,063	17,250	0	36,325	81,964
2000	December	913	2,599	19,501	12,480	0	366	35,859	0	0	0	0	0	47,235	51,510
2000	January	124	2,345	18,512	12,763	0	254	33,998	0	0	0	0	0	23,459	30,864
2000	February	-204	774	3,783	8,316	0	37	12,910	0	0	0	0	0	2,116	10,205
2000	March	5,111	2,800	13,962	9,693	0	522	32,088	0	0	0	0	0	10,323	18,848
2000	April	7,672	9,920	22,691	10,986	0	1,796	53,065	0	17,750	16,998	21,576	0	20,241	83,289
2000	May	-2,109	3,909	6,875	11,400	0	24	22,207	0	424	438	462	6	30,667	44,799
2000	June	-2,308	-1,444	6,996	1,557	0	13	8,566	0	0	0	0	0	3,530	14,695
2000	July	3,022	9,218	22,104	14,396	3,667	2,235	54,642	0	0	0	0	0	108	1,643
2000	August	-2,743	-8,138	24,048	10,592	5,378	2,151	42,169	0	2,606	1,402	1,339	0	473	20,843
2000	September	4,727	2,014	35,296	8,191	7,339	1,436	59,004	0	0	0	0	0	21	6,263
2000	October	-4,832	23,870	52,354	8,692	13,804	4,141	102,860	0	15,749	13,779	11,968	0	0	48,102
2000	November	-14,707	0	0	1	1,178	382	1,562	0	0	0	0	0	1,956	31,197
2001	December	7,388	0	0	0	500	456	8,344	0	0	0	0	0	2,846	5,547
2001	January	4,273	0	0	0	106	5	4,384	0	0	0	0	0	1,624	2,980
2001	February	-1,098	-1,386	0	0	0	0	0	0	0	0	0	0	5,746	19,107
2001	March	-112	412	6,938	534	1,038	728	9,650	0	0	0	0	0	1,553	4,988
2001	April	-1,108	0	0	1,065	1,078	10	2,153	0	0	0	0	0	86	5,473
2001	May	-688	0		0	0	12	12	0	0	0	0	0	21	3,750
2001	June	-656	33		0	232	4,068	4,333	0	0	0	0	0	204	861
2001	July	360	-962		0	40,721	9,374	50,455	0	9,328	6,500	14,235	0	0	31,025
2001	August	-6,091	114		0	49,004	4,089	53,206	0	10,689	24,762	30,373	0	360	72,332
2001	September	-3,075	-338		1,085	56,018	7,401	64,504	0	11,435	11,006	10,790	0	0	36,644
	Inflow	43,137	100,890	323,902	141,281	180,063	52,303	Outflow	0	151,581	178,381	181,553	6	206,314	
	Outflow	-39,731	-18,501	0	0	0	0	Inflow	0	0	0	0	0	0	
Total								**841,576**							**885,941**

Note: Negative inflow values counted as outflow in sums; negative ouflow values counted as inflows in sums.

Table 2A-2-5. WCA-2 inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	S7	S10A	S10C	S10D	S10E	G335	NorthSpr	WCA2 Inflow	S11A	S11B	S11C	S34	S38	S141	S143	WCA2 Outflow
1999	October	63,709	83,599	84,432	73,559	0	0	3,268	308,568	0	65,732	63,705	50,436	4,903	7,333	0	192,110
1999	November	6,525	0	19,063	17,250	0	0	175	43,013	0	28,487	27,493	20,519	12,895	13,184	0	102,577
2000	December	985	0	0	0	0	0	0	1,937	0	-952	0	0	14,831	14,484	0	29,315
2000	January	2,656	0	0	0	0	0	0	2,656	0	0	0	0	14,675	14,028	0	28,703
2000	February	2,460	0	0	0	0	0	0	2,460	0	1,359	0	0	13,187	12,610	0	27,155
2000	March	2,352	0	0	0	0	0	276	2,628	0	13,966	0	0	8,061	10,828	0	43,707
2000	April	24,900	17,750	16,998	21,576	0	0	258	81,483	0	0	0	0	10,613	10,487	0	32,293
2000	May	19,803	424	438	462	6	0	0	21,134	0	17,504	0	0	20,150	14,900	0	74,164
2000	June	1,724	0	0	0	0	0	0	1,724	0	0	0	0	0	5,162	0	5,162
2000	July	8,952	0	0	0	0	0	212	9,168	0	20,791	0	0	0	0	-4	20,791
2000	August	10,106	2,606	1,402	1,339	0	0	166	15,624	0	19,785	0	0	0	456	-5	20,241
2000	September	20,713	0	0	0	0	0	718	21,431	0	0	0	0	0	195	0	195
2000	October	49,716	15,749	13,779	11,968	0	0	1,270	93,513	0	48,563	0	0	0	1,024	-1,031	49,587
2000	November	20,888	0	0	0	0	0	0	20,888	0	12,827	0	0	0	6,936	22	19,785
2001	December	8,452	0	0	0	0	0	0	8,452	0	0	0	0	0	4,761	0	4,761
2001	January	-6,113	0	0	0	0	0	0	0	0	0	0	0	0	6,146	0	12,259
2001	February	0	0	0	0	0	0	0	0	0	0	0	0	0	3,781	0	3,781
2001	March	5,297	0	0	0	0	0	0	5,297	0	0	0	0	0	0	0	0
2001	April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	May	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
2001	June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	July	6,236	9,328	6,500	14,235	0	42,059	0	78,359	0	8,428	10,612	22,733	0	0	0	41,772
2001	August	-8,850	10,689	24,762	30,373	0	33,914	755	101,950	0	42,970	42,091	53,823	0	0	-1,458	147,735
1900	September	9,627	11,435	11,006	10,790	0	49,288	1,307	94,912	0	7,585	12,196	8,928	0	0	-1,458	28,709
	Inflow	265,100	151,581	178,381	181,553	6	125,262	8,405	Outflow	0	287,996	156,097	156,438	99,315	126,316	22	
	Outflow	-14,963	0	0	0	0	0	0	Inflow	0	-952	0	0	0	0	-3,956	
Total									**915,197**								**884,803**

Note: Negative inflow values counted as outflow in sums; negative ouflow values counted as inflows in sums.

Table 2A-2-6. WCA-3 inflow and outflow during the 2000-2001 drought (ac-ft)

Year	Month	S140_TOT	S150_C	S8	S9_P	L4 cut	WCA3 Inflow	G69_C	S12_T	S142_C	S30_C	S31_C	S333	S343A_C	S343B_C	S344_C	WCA3 Outflow
1999	October	57,885	0	135,412	67,960		261,257	0	0	261,540	12,969	0	0	248	5,213	5,966	289,688
1999	November	20,109	0	11,621	25,430		57,160	0	0	339,134	15,873	662	206	690	6,053	6,495	373,317
2000	December	3,687	0	0	3,186		6,873	0	0	193,626	12,265	12,154	25,438	0	3,275	3,456	252,546
2000	January	0	34	246	79		359	0	0	90,307	0	11,244	34,877	34,318	0	0	170,747
2000	February	40	392	185	514		1,130	0	0	24,831	1,731	10,720	30,160	66,851	0	0	134,293
2000	March	-448	8,745	682	6,190		16,051	0	0	0	-434	4,912	2,337	22,534	0	0	30,231
2000	April	2,831	18,703	21,676	9,278		52,560	0	0	0	-71	0	6,973	31,074	0	0	38,047
2000	May	44	0	15,041	1,154		16,239	0	0	0	0	0	10,917	21,631	0	0	32,548
2000	June	5	1,731	14,886	14,091		30,712	0	0	0	0	0	0	11,776	0	0	11,776
2000	July	2,366	29,371	30,246	44,897		108,125	0	0	1,131	-1,245	0	0	8,509	0	0	9,640
2000	August	5,359	4,990	15,698	25,771	-236	51,839	0	-21	20,243	926	0	0	4,402	0	0	25,808
2000	September	15,572	803	38,703	22,183	10,648	92,689	0	-385	5,260	-4,396	0	0	7,158	0	0	12,419
2000	October	36,863	1,529	51,892	41,175	24,488	162,276	0	99	13,416	-6,329	0	0	1,386	0	0	14,902
2000	November	2,698	0	430	3,466	6,020	12,719	0	-106	4,108	992	0	0	19,841	0	0	24,941
2001	December	0	0	0	8,497	7,974	17,859	0	-128	0	-1,260	0	19	9,162	0	0	9,181
2001	January	18	0	278	3,617	9,882	15,158	0	-98	3,027	-1,263	0	71	3,709	0	0	6,807
2001	February	0	0	82	0	8,879	11,784	0	-59	413	-2,765	0	0	490	0	0	903
2001	March	1	859	1,133	7,191	9,460	20,738	0	-151	0	-1,942	0	0	0	0	0	0
2001	April	0	0	561	125	8,049	13,500	0	-180	0	-4,585	0	0	1,704	0	0	1,704
2001	May	0	0	0	24,132	5,322	36,511	0	-136	0	-6,920	0	0	0	1	104	105
2001	June	6,401	0	0	24,686	11,177	50,122	0	-160	666	-7,698	0	0	1,135	0	0	1,802
2001	July	14,755	3,139	2,986	34,101	9,962	72,787	0	191	1,250	-7,843	0	0	270	0	0	1,710
2001	August	15,074	104	7,518	43,746	10,778	79,495	0	-303	62,771	-1,973	0	0	73,043	2,839	3,096	143,381
1900	September	21,393	1,007	34,337	40,046	38,074	135,915	0	48	94,816	-1,057	0	0	14,095	3,945	4,223	120,442
	Inflow	205,100	71,407	383,612	451,516	160,712	Outflow	0	337	1,116,540	44,756	39,691	111,000	334,026	21,326	23,340	
	Outflow	-448	0	0	0	-236	Inflow	0	-1,727	0	-49,781	0	0	0	0	0	
Total							**1,323,856**										**1,706,935**

Note: Negative inflow values counted as outflow in sums; negative ouflow values counted as inflows in sums.

Table 2A-2-7. Coastal outflow during the 2000-2001 drought (ac-ft)

Year	Month	S99_S	S49_S	S97_S	S80_S	S46_S	S44_S	S155_S	S40_S	S41_S	G56_S	G57_S
1999	October	76,704	74,303	73,739	116,471	40,035	23,057	127,653	38,951	55,592	49,116	2,462
1999	November	3,530	8,082	2,743	104,682	8,991	8,239	69,877	8,137	10,258	42,587	680
2000	December	5	32	0	46,195	386	4,605	51,578	728	1,071	43,998	288
2000	January	5	2	13	22,316	1	3,639	28,713	1,125	1,683	20,211	116
2000	February	4	16	0	2,013	0	3,335	4,604	0	221	1,425	21
2000	March	2	0	0	4,899	0	3,148	4,984	3,498	4,440	13,883	96
2000	April	7	7	1,433	39,769	195	4,812	19,359	6,711	10,863	22,502	157
2000	May	0	0	0	87,759	0	1,973	4,330	520	1,029	20,666	81
2000	June	542	368	3	2,083	0	1,051	1,738	662	1,187	1,085	455
2000	July	13,874	12,558	8,008	2,152	0	5,069	19,462	296	1,220	8,205	478
2000	August	8,017	11,857	10,742	2,152	0	3,838	14,656	1,581	4,793	7,285	346
2000	September	4,197	8,351	5,281	2,083	1	4,807	8,048	5,045	13,420	6,006	284
2000	October	10,986	17,099	10,236	2,152	9,086	11,810	38,380	16,369	26,804	20,199	1,453
2000	November	0	0	0	2,083	35	7,458	8,319	5,615	10,385	3,135	125
2001	December	0	0	0	2,152	2	5,247	11,729	269	2,656	2,300	62
2001	January	0	0	0	2,152	0	3,842	377	5	474	1,499	3
2001	February	0	0	0	1,944	0	3,235	0	7	0	1,324	0
2001	March	0	0	0	2,152	0	5,744	7,724	591	3,713	1,294	281
2001	April	0	0	0	2,083	0	4,241	267	71	318	0	43
2001	May	0	0	0	2,152	0	2,243	0	1	344	0	264
2001	June	9,175	9,141	2,513	2,083	408	4,803	20,976	2,988	11,707	1,114	340
2001	July	62,454	53,687	19,244	2,152	8,845	9,243	63,805	5,397	23,752	12,595	540
2001	August	46,919	43,255	19,503	2,152	26,563	16,527	60,283	17,078	25,156	21,499	1,082
2001	September	38,920	40,628	42,100	2,083	21,811	22,628	76,135	24,606	39,030	22,351	1,465
Total		**275,340**	**279,383**	**195,558**	**457,912**	**116,360**	**164,595**	**642,998**	**140,251**	**250,114**	**324,280**	**11,122**

Table 2A-2-7. Coastal outflow during the 2000-2001 drought, continued

Year	Month	S37A_S	S36_S	S33_S	G54_S	S13_P	S13_S	S29_S	G58_C	S28_S	S27_S	S26_S
1999	October	43,370	13,295	3,136	10,262	13,641	10,983	192,692	39,222	1,141	32,208	8,004
1999	November	17,940	6,297	220	16,721	1,581	12,937	111,822	22,490	32	5,868	11,868
1999	December	11,075	4,708	0	13,483	0	20,294	98,874	16,476	0	0	15,305
2000	January	9,601	2,764	0	11,405	27	15,751	78,673	11,225	0	304	20,686
2000	February	7,840	1,970	0	8,646	0	12,252	60,951	9,184	0	2,299	15,611
2000	March	11,154	3,560	70	8,244	0	13,137	71,925	10,099	4	5,982	1,180
2000	April	6,645	2,544	215	9,809	0	12,663	63,536	19,609	132	9,341	7,244
2000	May	6,256	746	0	12,024	0	4,146	46,122	2,074	31	1,723	8,391
2000	June	1,772	1,547	0	2,405	0	8,248	28,615	29,255	153	11,618	3,053
2000	July	4,413	6,742	254	12,481	0	8,538	65,267	22,291	88	14,219	5,136
2000	August	2,414	3,584	0	6,716	0	5,777	37,363	27,892	39	9,953	6,614
2000	September	4,494	3,506	0	1,469	587	6,779	33,953	20,626	63	10,481	5,703
2000	October	14,049	6,766	996	3,064	10,180	6,249	84,807	58,871	-1,679	33,990	11,212
2000	November	0	0	0	0	585	2,613	6,592	2,802	0	1,468	1,797
2000	December	612	870	15	325	0	5,246	14,143	12,472	-14	5,030	2,369
2001	January	0	1	5	0	0	2,560	5,094	0	0	0	19
2001	February	0	0	0	0	1	684	1,360	0	0	0	0
2001	March	212	0	153	188	0	3,092	7,787	1,331	16	976	23
2001	April	0	0	0	0	0	1,534	3,128	5,141	11	1,940	67
2001	May	186	116	49	905	0	4,923	12,781	11,860	229	9,846	306
2001	June	3,312	1	23	0	0	4,290	15,801	18,714	128	6,330	2,076
2001	July	7,267	4,243	498	2,022	2	6,676	42,146	29,711	143	11,611	4,741
2001	August	13,557	5,751	1,080	7,657	5,370	3,208	74,787	40,401	193	10,930	9,900
2001	September	23,441	8,634	2,007	5,586	5,575	5,542	103,636	43,684	-868	19,894	8,829
Total		**189,611**	**77,646**	**8,721**	**133,412**	**37,550**	**178,122**	**1,261,854**	**455,431**	**-157**	**206,011**	**150,133**

Table 2A-2-7. Coastal outflow during the 2000-2001 drought (ac-ft), continued

Year	Month	S25_C	S25B_S	G93	S22_S	S123_S	S21_S	S21A_S	S20G_S	S20F_S	S197_C	East Coast To Tide	West Coast To Tide S79_S
1999	October	37,896	391	40,161	7,919	40,504	32,013	-12,246	31,200	4,098	43,242	1,271,215	287,437
1999	November	14,088	121	24,424	1,414	16,495	1,883	10,995	8,132	1,694	12,960	567,788	239,173
1999	December	9,180	16	25,367	0	4,985	1,603	2,248	7,900	63	10,922	391,386	110,116
2000	January	4,856	0	3,083	0	420	925	1,399	5,982	0	8,444	253,367	51,090
2000	February	5,348	160	12,039	0	452	677	2,154	4,651	2	5,933	161,809	1,075
2000	March	1,647	48	7,118	1	32	7	1,487	3,501	16	6,053	180,215	22,383
2000	April	5,066	36	11,230	529	7,179	9	4,238	3,757	90	5,579	275,265	80,497
2000	May	3,349	49	711	18	196	0	1,166	1,074	0	694	205,129	174,020
2000	June	15,990	330	9,650	0	78	8	3,581	4,013	239	7,685	137,412	29,263
2000	July	16,732	557	6,665	1	3,286	130	12,002	6,663	1,173	11,368	269,328	49,908
2000	August	14,369	107	17,842	255	6,072	1,221	17,450	8,076	1,323	18,830	251,164	29,470
2000	September	17,066	642	26,118	1,967	8,400	2,586	11,553	8,214	1,195	14,752	237,676	106,380
2000	October	33,875	2,700	38,517	6,915	26,504	25,338	19,912	29,166	5,042	42,236	623,282	49,218
2000	November	12,556	234	16,655	0	210	6	2,938	4,703	503	8,854	99,669	9,160
2000	December	16,132	790	16,316	1,278	12,625	3,242	11,705	13,728	2,844	20,246	164,391	0
2001	January	9,282	0	4,382	0	0	0	1,296	3,432	0	5,186	39,608	9,449
2001	February	5,008	0	0	0	0	0	0	921	0	144	14,628	0
2001	March	3,245	41	0	0	0	0	145	2,128	0	101	40,938	1,888
2001	April	8,328	3	0	0	0	0	717	1,500	102	0	29,495	1,966
2001	May	15,968	868	3,309	0	834	595	5,250	2,352	419	1,993	77,795	8,102
2001	June	15,551	540	10,399	-13	2,533	613	4,765	4,910	1,205	10,061	166,486	29,419
2001	July	18,078	386	22,726	31	13,744	2,369	17,859	9,700	1,902	17,585	475,155	130,772
2001	August	19,290	385	24,364	435	13,341	2,173	32,492	10,404	1,301	23,169	580,203	179,570
2001	September	24,988	2,276	23,504	1,847	25,413	13,825	18,584	19,120	3,516	32,460	723,247	324,468
Total		**327,888**	**10,678**	**344,578**	**22,597**	**183,302**	**89,223**	**171,691**	**195,228**	**26,726**	**308,494**	**7,236,651**	**1,924,825**

Table 2A-2-8. ENP inflow during the 2000-2001 drought (ac-ft)

Year	Month	S18C	S197_C	S18C_net	S12_T	S332_P	S332B_P	S332D_P	S333	ENP Inflow
1999	October	52,955	37,410	15,545	261,540	32,804	0	12,538	248	413,040
1999	November	15,451	0	15,451	339,134	31,644	0	6,285	690	408,655
2000	December	11,883	0	11,883	193,626	32,837	0	0	0	250,229
2000	January	15,612	0	15,612	90,307	33,000	0	24,796	34,318	213,646
2000	February	9,848	0	9,848	24,831	19,735	0	16,595	66,851	147,707
2000	March	5,691	0	5,691	0	1,565	0	0	22,534	35,481
2000	April	5,820	0	5,820	0	1,927	0	0	31,074	44,640
2000	May	612	0	612	0	1,024	0	229	21,631	24,108
2000	June	8,995	0	8,995	0	304	0	762	11,776	30,831
2000	July	21,128	0	21,128	1,131	46	0	18,158	8,509	70,099
2000	August	31,267	0	31,267	20,243	1	0	21,729	4,402	108,910
2000	September	31,910	1,273	30,637	5,260	0	0	24,615	7,158	100,854
2000	October	46,380	24,220	22,160	13,416	0	0	25,433	1,386	132,994
2000	November	4,285	0	4,285	4,108	1	0	8,425	19,841	40,944
2001	December	6,958	0	6,958	0	1	1,726	0	9,162	24,804
2001	January	157	0	157	3,027	0	0	0	3,709	7,050
2001	February	2	0	2	413	0	0	0	490	907
2001	March	0	0	0	0	0	0	0	0	0
2001	April	212	0	212	0	0	0	0	1,704	2,128
2001	May	1,089	0	1,089	0	0	0	0	0	2,178
2001	June	4,012	0	4,012	666	0	0	740	1,135	10,565
2001	July	19,689	0	19,689	1,250	0	3,967	13,435	270	58,299
2001	August	30,155	4,936	25,219	62,771	0	6,933	16,970	73,043	220,026
2001	September	29,371	2,410	26,962	94,816	0	14,364	25,084	14,095	207,101
Total										**2,555,198**